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Engineer Research and
Development Center

Oakland Harbor Navigation Study

Gary C. Lynch and Peggy Van Norman

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Oakland Harbor Navigation Study

by Gary C. Lynch, Peggy Van Norman

Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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Preface

This navigation study was performed by the Coastal and Hydraulics Laboratory (CHL) of the Engineer Research and Development Center (ERDC) for the U.S. Army Engineer District, San Francisco. Navigation simulation exercises performed with the San Francisco Bar Pilots were conducted with the Navigation Branch Ship/Tow Simulator ending 2 July 1999. Current modeling was conducted by the Tidal Hydraulics Branch of the Estuary and Hydrosiences Division, CHL.

The navigation study was performed by Mr. Gary C. Lynch, research hydraulic engineer of the Navigation Branch, Navigation and Harbors Division, CHL. Ms. Donna Derrick and Ms. Peggy Van Norman, civil engineering technicians of the Navigation Branch, assisted in the study. The hydrodynamic modeling study that supplied the harbor current patterns for this study was performed by Mr. Ben Brown of the Tidal Hydraulics Branch of the Estuary and Hydrosiences Division. This report was prepared by Mr. Lynch and Ms. Van Norman, assisted by Mrs. Dinah N. McComas, under the direction of Dr. Sandra Knight, Chief, Navigation Branch.

Acknowledgment is made to Mr. Keiso K. Morimoto of the U.S. Army Engineer District, San Francisco, and Mr. Len Cardoza of the Oakland Port Authority, for cooperation and assistance throughout the investigation. Special thanks goes to the San Francisco Bar Pilots Association for providing pilot participation and insight during the study.

At the time of publication of this report the Director of ERDC was Dr. James R. Houston. The Commander was COL Robin R. Cababa, EN.

Conversion Factors, Non-SI Units to SI Units of Measurement

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
knots (international)	0.5144444	meters per second
miles (U.S. statute)	1.609347	kilometers
miles (U.S. nautical)	1.852	kilometers

1 Introduction

Oakland Harbor¹

The Port of Oakland and the Oakland Inner and Outer Harbors are located on the eastern side of the San Francisco Bay in the counties of Alameda and San Francisco, California (Figure 1). The Port is a transportation and distribution center that provides access to marine terminals specializing in containerized shipments. Navigation in Oakland Harbor is carried out only in the Outer and the Inner Harbors. The tidal range between mean lower low water (mllw) and mean higher high water (mhhw) is approximately 6.4 ft (from approximately 0 ft mllw to +6.4 ft mllw).

The Outer Harbor is located immediately south of the San Francisco-Oakland Bay Bridge (Figure 1). The authorized Federal channel in the Outer Harbor is maintained at -42 ft mllw and provides access to the Port of Oakland's terminals which operate with container, break-bulk, and roll-on/roll-off deep-draft vessels. The Outer Harbor Channel is 42-ft deep and 8,700-ft long up to the Outer Harbor turning basin. It is 42-ft deep and 4,000-ft long north of the Outer Harbor turning basin. In addition, there is a 1,300-foot long dogleg extending east from the northern end of the Outer Harbor channel. The western portion of the Outer Harbor channel narrows from 1,000 ft at the end of the Entrance channel to 600-ft wide 7,100 ft east of the Entrance channel, where the Outer Harbor channel bends to the east. The Outer Harbor channel then widens over the next 1,600 ft to meet the west-end of the turning basin. The northern portion of the Outer Harbor channel is 900-ft wide along its entire length; the dogleg narrows from 800 ft at its entrance to 600 ft at its eastern end. The Outer Harbor turning basin is located at the main bend in the Outer Harbor channel, with its mouth located approximately 8,700 ft east of the eastern end of the Entrance channel. It is currently maintained at 42-ft deep and 1,480-ft wide.

The Inner Harbor (Figure 1) separates the cities of Alameda and Oakland and was developed from the natural estuary of San Antonio Creek extending to Brooklyn Basin. The Entrance Reach and Inner Harbor Reach are maintained at -42 ft mllw. Upper reaches of the Inner Harbor serve privately owned facilities along the estuary, and are maintained at lesser depths. The Inner Harbor Channel is divided into six segments. The first and second segments (Entrance Reach and

¹ This information was obtained primarily from the Port of Oakland's website. <http://www.portofoakland.com>.

Inner Harbor Reach) are proposed to be part of the navigation improvement project. This portion of the channel is currently between 38-ft and 42-ft deep, and extends 18,800 ft from the end of the Entrance channel to the Inner Harbor turning basin. A small portion of the Inner Harbor Reach extends 1,700 ft east of the Inner Harbor turning basin. The Inner Harbor channel narrows from 2,200-ft at the start of the Entrance Reach to 480-ft immediately south of the former Fleet and Industrial Supply Center Oakland, and then widens again to 700 ft at the mouth of the turning basin. The Inner Harbor channel east of the turning basin narrows from 800 ft at the end of the turning basin to 700 ft at the end of the Inner Harbor Reach.

The Inner Harbor Turning Basin is located approximately 18,800 ft east of the entrance into Inner Harbor and is 42-ft deep and 1,200-ft wide. Vessel traffic access to the San Francisco Bay is through the San Francisco Bar channel. The approximate location of the Bar channel is shown in Figure 1. This channel is maintained at -55 ft mllw. However, tidal conditions, channel depth, and swelling restrict operating vessels to a draft of -50 ft mllw.

Navigation Problems

Navigation problems in Oakland Harbor arise from primarily two sources: a) the crosscurrents or shear at the entrance of Inner and Outer Harbor (Figure 2), and b) the restrictions in the size of the turning basins for these two Harbors. For Outer Harbor, the flood current poses a greater problem than the ebb tide. The flood tide pushes the vessel entering Outer Harbor towards Ben E. Nutter Marine Container Terminal (PCT) and shears the vessel's stern even more in that direction once the bow has entered the fairly protected waters in front of the terminals. Inner Harbor is just the opposite, with the ebb tide being more difficult. However, both tidal conditions have their own considerations for each harbor.

A deepening project to -50 ft is proposed (Figure 3) to accommodate the Extended K-class containership, to reduce tidal-caused delays associated with containership passages, and to increase navigational safety. The most critical aspect of the deepening project is the Inner Harbor Turning Basin. Size constraints on this area of the project will require careful modeling and analysis to ensure a safe yet feasible turning basin. Therefore, a ship simulation model was conducted for the proposed project.

2 Navigation Model

Objective and Scope of Navigation Study

The simulation model for the Oakland Harbor Navigation Study extended from just North of the Bay Bridge (Figure 3) and encompassed the Bar Channel, all the Outer Harbor and all the Inner Harbor to just upstream of Howard Terminal. The following steps were taken during the study and will be further explained in the following section:

- a.* Site visit of Oakland Harbor and San Francisco Bay area.
- b.* Preparation of visual and radar database files.
- c.* Construction of math model of Extended K-class containership for simulation.
- d.* Incorporation of currents and depths from the Hydrodynamic Model.
- e.* Validation of the simulation model for existing conditions and review of the Inner Harbor Turning Basin design plan with the assistance of two San Francisco Bar Pilots.
- f.* Conducting navigation simulation exercises on the new designs for Inner and Outer Harbor with the assistance of two San Francisco Bar Pilots per week for three weeks. Six pilots participated in the design simulation exercises.
- g.* Analyzing and reviewing data collected to prepare report on findings.

Site Visit

On 22 February 1999, Ms. Peggy Van Norman and Mr. Gary Lynch, of the Coastal and Hydraulics Laboratory (CHL) traveled to Oakland, CA, for a site visit to finalize the limits of the navigation simulation project and to transit the study area. Once in Oakland, a meeting with the San Francisco Bar Pilots was arranged with the help of the Port of Oakland. Video and 35mm still photos of the area were obtained with the help and assistance of the Bar Pilots.

CHL personnel met with Mr. Len Cardoza, Port of Oakland, on the morning of 23 February 1999. Mr. Cardoza discussed two possible configurations of the Outer Harbor improvements (Figure 4), and the improvements planned for Inner Harbor (Figure 5). CHL personnel and Mr. Cardoza then traveled to the San Francisco District Office for an Oakland Harbor 50-ft Deepening Agenda Meeting. Representatives from CHL, Port of Oakland, the District, and Gaia Consulting, Inc. were in attendance. During this meeting it was reiterated that the Middle Harbor was to be blocked off from the San Francisco Bay by a submerged rock wall and the harbor filled in to approximately 9 ft. It was also noted that the turning basin of Inner Harbor was the most critical aspect of the project to the Port of Oakland. On the afternoon of the 23 February 1999, CHL personnel and Mr. Cardoza met with Capt. Eric Dohm of the San Francisco Bar Pilots. Several important points were made during these two meetings:

- a. Ships coming into the harbor have two tugs assisting them from the entrance of the harbor.
- b. To set up properly, the study transit will need to start north of the San Francisco – Oakland Bay Bridge.
- c. The entrances to both Inner and Outer Harbors have a problem with crosscurrents that line up with the main shoreline, causing the ship to slip as it enters the harbor. Of the two, the Outer Harbor has the biggest shear caused by these currents. The crosscurrents occur on both flood and ebb tides.
- d. There is a question as to what affect filling in Middle Harbor will have on the crosscurrents.
- e. The submerged wall at Middle Harbor could also have an affect upon ships entering Inner Harbor.
- f. Ships back into Outer Harbor on occasion. However, this was not considered normal operation.
- g. The turning basin in Inner Harbor is critical to the project.
- h. The design ship for the project is the S Class Containership, also called the Extended K Class. Dimensions are 1,139-ft length overall (LOA), 140-ft beam, and 48-ft draft.

After discussions with Capt. Dohm, the San Francisco Pilot Association permitted CHL personnel and Mr. Cardoza to board one of their pilot boats and transit the study area. Video footage and 35 mm photos were taken of Outer Harbor, the San Francisco – Oakland Bay Bridge, and part of Inner Harbor. The pilot boat was unavailable for the rest of the afternoon to complete reconnaissance of the Inner Harbor area. Capt. Dohm made arrangements for the CHL personnel and Mr. Cardoza to ride the containership President Polk of American President Lines (APL) shipping line on 24 February 1999 into Inner Harbor. The

containership would make the turn in the Inner Harbor turning basin, providing an excellent opportunity to acquire the remaining photo footage needed.

In the early afternoon of 24 February 1999, CHL personnel and Mr. Cardoza met with Capt. Asmund Gjevik. They boarded the pilot boat and then the President Polk containership of the APL shipping line. Capt. Gjevik pointed out objects needed by the pilots for the simulation visual scene and reiterated the problem areas for the study. The remaining video and 35 mm footage needed was taken during this transit (Figures 6 and 7).

Simulation Database Generation

The data required for the Oakland Harbor Navigation Simulation Study included channel geometry, bottom topography (bathymetry), channel currents, existing and design ship parameters, visual data of the physical scene, and radar for existing and plan conditions.

The physical scene database consisted of the water, land, navigational aids, buildings, bridges, and any other land or watermark that pilots need to comfortably maneuver the vessel in the virtual harbor. These objects are mostly taken from the 35mm and video footage shot during the site visit. However, navigation charts, District information, and pilot input are also valuable assets in the making of these databases. The water and land made up a base structure called the "terrain" upon which all other objects were placed. The terrain's form was a generalized depiction of the elevation and coloring of the study area. Figure 8 shows a generalized containership terminal from the Oakland Harbor simulation. These terminals were placed in the correct location with the correct shape and orientation; however, the cranes and containers were simplified. Figure 9 shows the Inner Harbor Turning Basin. To optimize the simulation, most objects in the visual scene are generalized. However, placement of the channel bank lines, navigational aids, and pertinent navigational structures have little room for error. Pilots are capable of filling in the details of a simplified structure, but they cannot create the placement of each defining point in a visual scene.

The radar database came from the digitized land outline of Navigation Chart 18650. Navigational aids were placed according to chart, Coast Guard, and pilot information. The radar, a simple vector image, was adjustable between three ranges: 0.5, 0.75, and 1.5 miles. A fixed 0.25-mile range radar is also used in simulation, for docking procedures and to view tugboat operation.

Channel geometry and bathymetry were created from both the hydrographic surveys supplied by the District and the Port of Oakland and the information received from the hydrodynamic model done at CHL. This group of files also includes the current direction and magnitude information for each simulation scenario.

Description of Typical Simulation

The CHL Ship/Tow Simulator configuration is shown in Figure 10. Once the databases are completed they are displayed as follows:

- a. The visual scene is shown on the three large-screen projectors by the Silicon Graphics Onyx.
- b. The radar image is displayed on the ship console (as shown in Figure 11).
- c. Navigational parameters are shown on the ship console (as shown in Figures 12-13).

The pilot sits in front of the ship console to control the ship's engine and rudder and to observe the consequences of those settings. The first several runs of each week were used to familiarize the pilots with the simulator. After the familiarization time, the actual simulation exercises began. The pilots alternate between transits if they need a break between runs; otherwise, both simulators are used to make runs simultaneously. Pilots must use caution during the simulations to maneuver only in ways that a real vessel would. In the hands of an experienced pilot, the simulated ship/channel environment behaves realistically. However, it is a tool that can give biased results by maneuvering in ways that real vessels cannot. The pilots are aware of these limitations and use the simulator accordingly.

Oakland Harbor Validation

Oakland Harbor validation took seven days. Two days with the pilots were used to accomplish design work for the development of the Inner Harbor Turning Basin. During validation the pilots changed several things, the most noteworthy of which are listed below:

- a. Changed the placement of the "shadow," or lessening of the currents, south of Yerba Buena Island. This "shadow" is caused by the flow separating around the island. The pilots said they experience this shadow in a slightly different place in real life than the hydrodynamic model produced so the shadow was moved accordingly.
- b. Updated the location or installation of several navigational aids not on the navigation chart.
- c. Added "feeder" barges to the containerships docked in Outer Harbor. These barges are used to refuel the containerships and take up an extra 100-150 ft which would normally be available to the piloted ship for maneuvering.

Oakland Harbor Simulation Exercises

The Oakland Harbor simulation exercises that were performed are listed in the table below:

Table 1 Oakland Harbor Simulation Exercise			
CHANNEL	LOCATION	DIRECTION	CURRENT DIRECTION
EXISTING	OUTER HARBOR	INBOUND	FLOOD
EXISTING	OUTER HARBOR	OUTBOUND	FLOOD
EXISTING	OUTER HARBOR	INBOUND	EBB
EXISTING	OUTER HARBOR	OUTBOUND	EBB
PLAN 1	OUTER HARBOR	INBOUND	FLOOD
PLAN 1	OUTER HARBOR	OUTBOUND	FLOOD
PLAN 1	OUTER HARBOR	INBOUND	EBB
PLAN 1	OUTER HARBOR	OUTBOUND	EBB
EXISTING	INNER HARBOR	INBOUND	FLOOD
EXISTING	INNER HARBOR	OUTBOUND	FLOOD
EXISTING	INNER HARBOR	INBOUND	EBB
EXISTING	INNER HARBOR	OUTBOUND	EBB
PLAN 1	INNER HARBOR	INBOUND	FLOOD
PLAN 1	INNER HARBOR	OUTBOUND	FLOOD
PLAN 1	INNER HARBOR	INBOUND	EBB
PLAN 1	INNER HARBOR	OUTBOUND	EBB

Starting positions for the inbound and outbound runs are shown in Figure 14. Each exercise was performed by as many of the six San Francisco Bar Pilots who participated in the navigation study as time allowed. If any additional time remained during the week it was used to conduct some of the exercises over again with a crosswind.

3 Results

The method used in this report to present results for the Oakland Harbor Navigation Study is the track plots of the pilot's simulation exercises, an example of which is shown in Figure 15. While this form of output visualization seems to show the information needed, such as the ship's position in the channel, its relative angle, etc., several things should be noted regarding the vessel, the pilot, and the simulation.

Two design vessels were used for these exercises. The 1143-ft LOA containership was used for the design condition exercises. The 980-ft LOA containership was used for the existing condition exercises. This ship was simulated fully loaded with containers, which limits visibility for up to a quarter of a mile in front of the bow of the vessel both in real life and in the simulation. This limitation can be reduced by the pilot walking out on the wing to look from the side of the vessel, which they do during maneuvering. It can also be somewhat remedied by placing a man out on the quarter to judge distances for the pilot during a turn. Neither of these two remedies is a complete solution. Radar also is not an answer for this problem, since radar can be inaccurate in close quarters. Global Positioning System (GPS) could help with this, but GPS systems are still not widely used in the shipping industry. The end result is that even though the ship track may appear to be quite some distance away from an obstacle, the pilot can only judge these distances by experience, and even then he can only approximate. Therefore, these distances should not be narrowed to an extreme.

The simulator cannot truly represent three-dimensional spatial perspective on its flat, two-dimensional screens. This results in some loss of depth perception, although some visual methods are used to preserve as much as possible. For this reason, the simulator's radar image is a crisp clear line image (Figure 16) unlike the fuzzy images found on most real radar screens. This clear image allows the pilot to have additional input for gauging distances and angles. However, it also gives the pilot an unfair advantage during turning maneuvers. For the Oakland Harbor Navigation Study, the pilots were instructed not to use the radar except to quickly check distances in an effort to simulate the input of a man placed on the quarter. Most often, however, the pilots would "walk out on the wing," thereby changing the view on the simulator screen, and gauging distances in that manner.

Many things beyond those results that can be graphically displayed must be taken into consideration when interpreting the results of any navigation

simulation. Descriptions and evaluations related to these considerations will be presented in the text as the plates are discussed.

Results of the Simulation Exercises

The results of the simulation exercises were split into four areas of interest (Figure 17). Area 1 covers the entire Outer Harbor transit from the entrance channel to the Turning Basin. Area 2 focuses on the terminal maneuvering and the Turning Basin itself. Area 3 covers the entrance to Inner Harbor, and Area 4 concerns just the Inner Harbor turning basin.

Plates for all runs have been included in this report for completeness. Highlights of the exercises as well as the trends represented in the exercises as a whole are explained in the text.

Area 1 and Area 2 Results (Outer Harbor)

Plates 1 - 45 show the Outer Harbor track plots. In general, the harbor was approached from the southern side of the entrance channel during ebb tide, allowing the vessel to sweep to the middle or northern side as it came into the harbor. On the flood tide, the northern side of the channel was steered for, allowing plenty of room for the vessel to come back to the south. With the crosscurrent in this area being 2.5 knots on a fairly regular basis, the vessel can have a considerable set coming into the entrance of the harbor. This was the reason the feeder barge was added to the containership docked at PCT on the design exercises. Once inside the protection of the docks, very little current is felt for the transit up to the turning basin. Once again, feeder barges are commonly hooked up to the containerships docked in this area, and were added to the design tests.

Plates 1 - 23 show the transit into Outer Harbor from the entrance channel, Area 1, up through the turning basin. Plates 1, 6, 11, and 16 show composite track plots for existing inbound ebb and flood and Plan ebb and flood, respectively. Plate 21 shows composites for the Plan outbound ebb. From the track plots it can be seen that none of the pilots encroach upon the channel just northwest of PCT (Figure 4), which is the part of the channel where the shear has its maximum effect on the vessel. An analysis of any of these plates for flood tide conditions shows just how much the crosscurrent affects the vessel entering the harbor. Plates 7 and 9 clearly show the crab angle of the ship, as do many other plates.

Plate 24 shows the composite of all pilots, Area 2, for the existing channel inbound ebb tide runs, plate 29 shows the same for the flood tide runs. Both composites show the tendency of the pilot to stay to the north side of the turning basin, most likely due to the visibility problems stated earlier.

Plate 34 shows the composite of all pilots for the plan inbound ebb tide runs. Plate 41 shows the same for the flood tide runs. Even if the feeder barges were not present, the design vessel does not have as much clearance as the existing vessel did. Notice also that the design vessels docked at the terminals encroach on the channel about 20 ft, further reducing the effective turning radius allowed the design vessel.

Area 3 Results (Inner Harbor Entrance)

Plates 46 - 93 show the entrance to Inner Harbor. Plates 46 - 62 are track plots for existing conditions and 63 - 93 are for the plan conditions. For both channel conditions the only aspect of note is the “jog” in the channel where it narrows inbound from navigation aid “R4”. This step causes the pilot to “check up” his entrance turn on the ebb tide, and causes him to carefully regulate the slide on the flood tide. This can be seen somewhat in the composite plates 46, 51, 63 and 69 as a shallow S-turn. However, the correction has already been made as the ship approaches the entrance, making it difficult to see in the track plots. Discussions with the pilots reinforce the point though, as well as observations of the transit being performed. This condition was slightly aggravated for the design ship simply due to the fact that the ship was longer and wider and therefore has more mass and inertia to maneuver.

Area 4 Results (Inner Harbor Turning Basin)

Plates 94 - 148 show the Inner Harbor turning exercises. Plates 94, 99, 106, and 109 show the composite runs for the existing channel configuration. For these transits a ship was docked at Schnitzer Steel and Howard Terminal. The track plots and the pilots’ reactions were consistent with turning maneuvers in the prototype. Two tugs were used for all turns. There are no excessive maneuvering problems in this area.

Plates 113, 124, 133, and 139 show the composite runs for the -50-ft design. As can be seen from these plates, the pilots use almost all the available area, including the area just downstream of Howard Terminal, which is currently not included in the -50-ft project design (Figure 18).

4 Conclusions and Recommendations

Outer Harbor

The widening completed just northwest of PCT seems sufficient for the design vessel. However, an additional widening of at least 50 ft on the north side of the turning basin would give some measure of relief to the turning vessel even when the feeder barges are not present.

Inner Harbor

If possible, the channel should be straightened from buoy "R4" into the entrance of Inner Harbor. This would keep vessels from having to perform the shallow S-curve prior to the entrance which could become an area of concern once the new terminals are in place at the entrance.

During the testing of the Inner Harbor Turning Basin it became apparent that the unusual asymmetric shape of the proposed basin, along with limiting factors on both sides of the channel, combine to encourage pilots to utilize a "sliding turn," meaning that the vessel never fully stops before it makes its turn. The existing basin has a more symmetric or circular shape allowing for the more standard and currently used method of operation -- stopping the vessel in the water and then turning it with the use of tugs. The "sliding turn" method of operation along with the track plots indicate that the areas excluded in Figure 18 should be available for turning in the proposed plan. The width of the Turning Basin, particularly on the Alameda side, should be as proposed in Figure 18.

The two areas originally designated as "not to be included" in the -50 ft project were determined to be useful for the logistics of the turning vessel. In particular, if a ship is not docked at Schnitzer Steel, a ship on the flood tide could begin his turn almost one-half a ship's length sooner than if this area were not included. Also, if a ship is docked at Howard Terminal, the area downstream is still a good pocket in which to stick the bow or stern of a turning vessel. The inclusion of these areas will also mean that the visual clue on the Oakland side of the basin that are already familiar to the pilots are still useful. The pilots were trying, for most of the exercises, to slide the stern up into safe water, hold it in

place, and swing the bow back around to make the turn. The “pocket” at Howard Terminal in the existing basin is ideal for this in the design, even with the ships docked by the basin. The presence of the ships at these two terminals does not exclude turning ships in the basin; but the inclusion of these two areas will improve turning maneuvers whether the ships are at these terminals or not. The pilots will have to determine the feasibility of the sliding turn versus normal turning operations. In either case, the maximum limits for the turning basin that can be used are necessary for this extended K-class ship, as approximated by the navigation channel as shown in Figure 19.

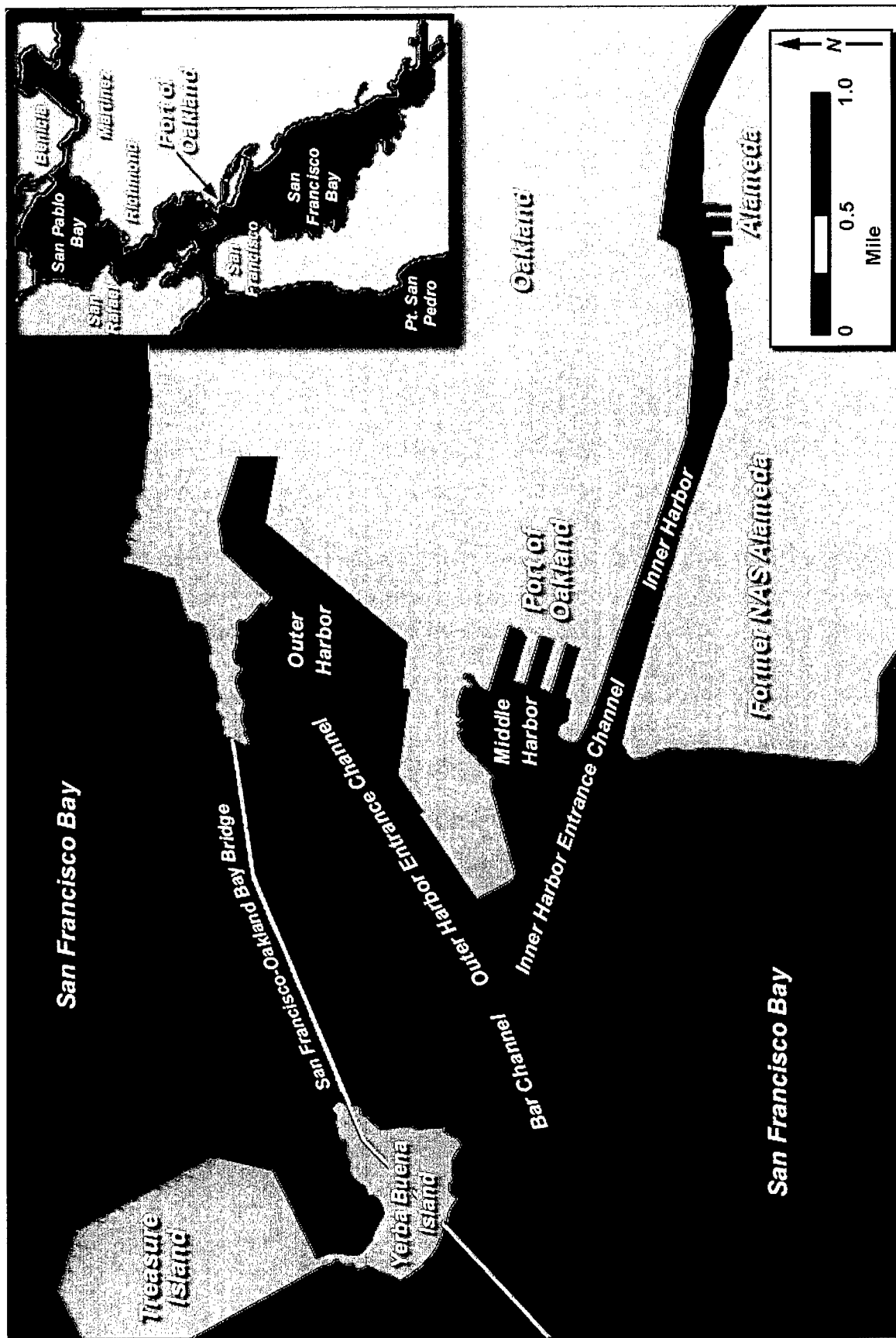


Figure 1. Oakland Harbor - location map

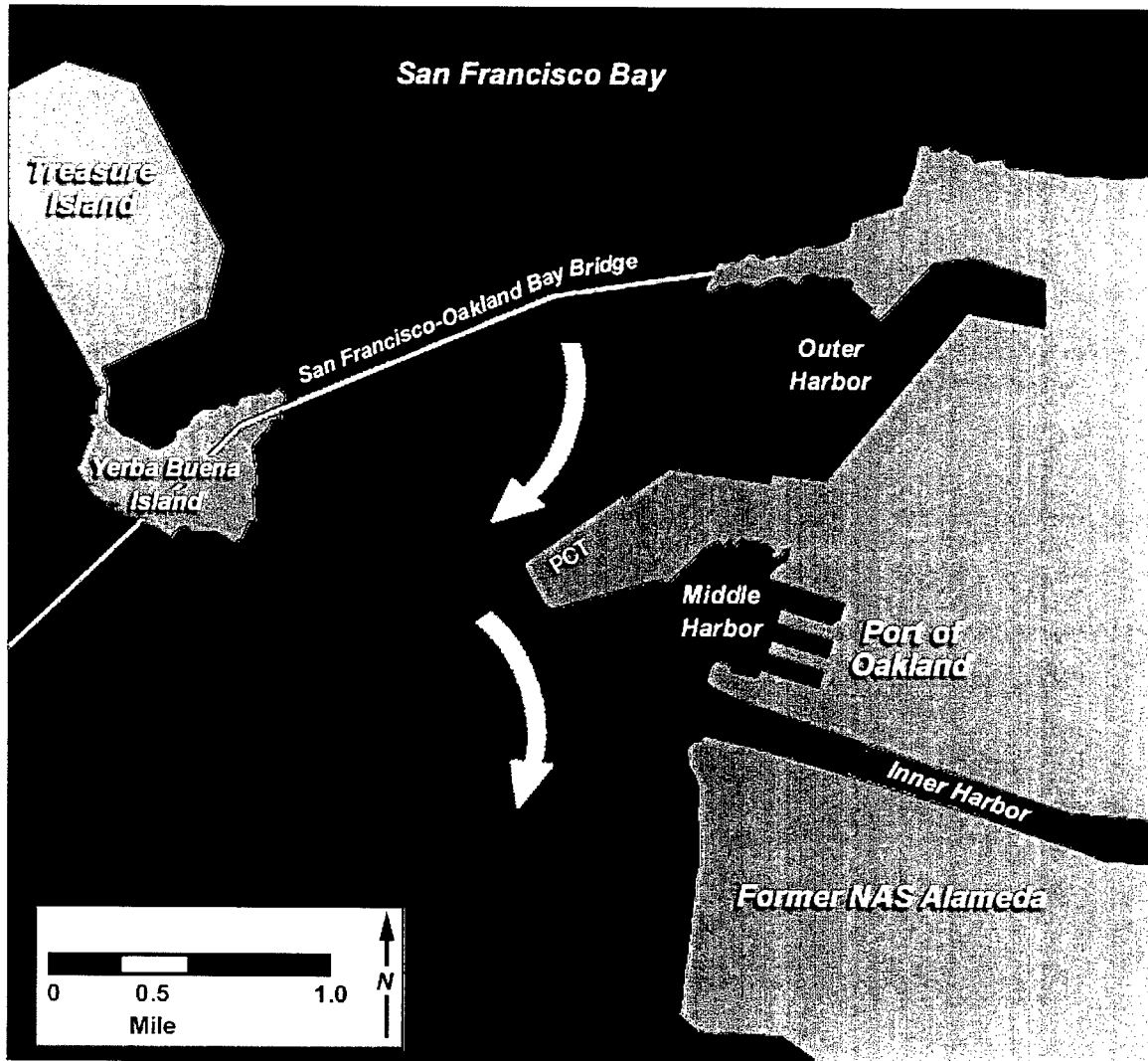


Figure 2. Oakland Harbor - location of shear currents

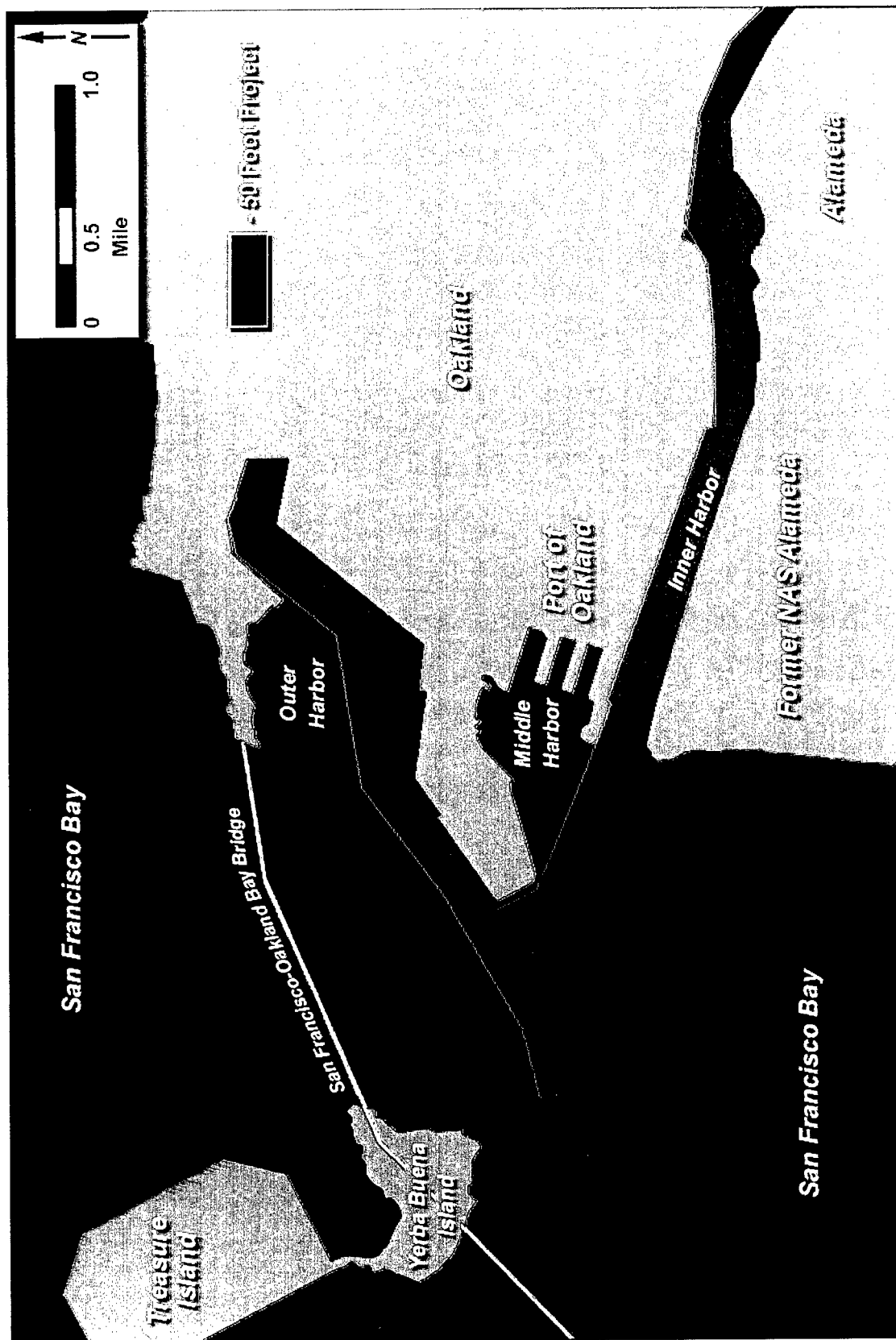
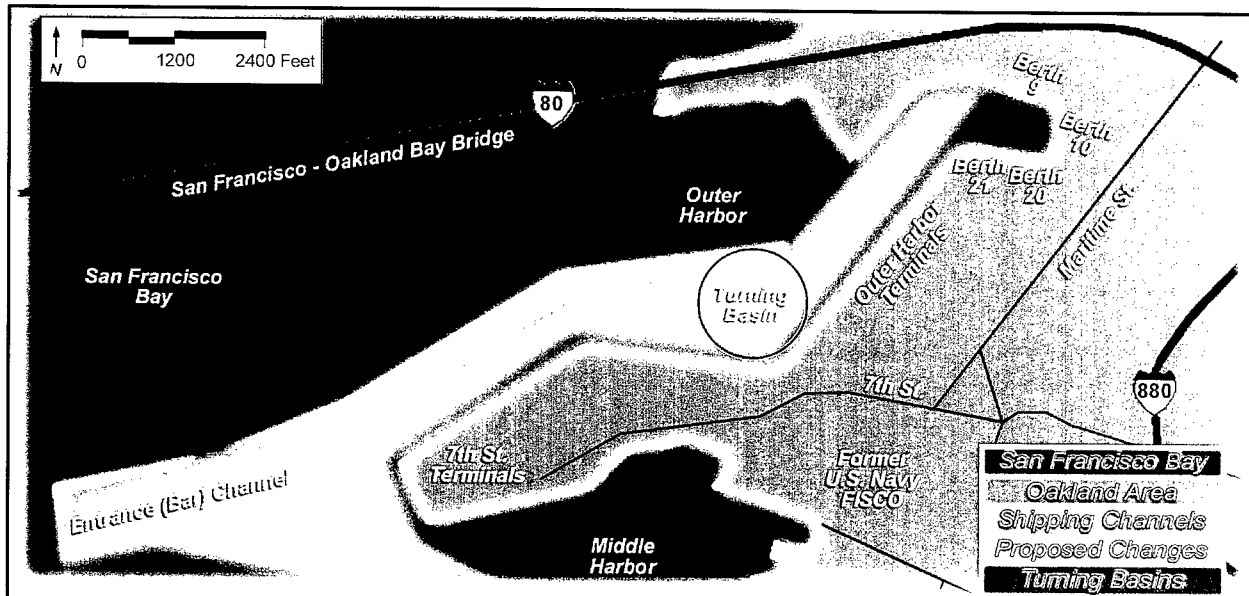


Figure 3. Oakland Harbor - 50 foot project



Port of Oakland Outer Harbor Navigation Improvements - Configuration 1

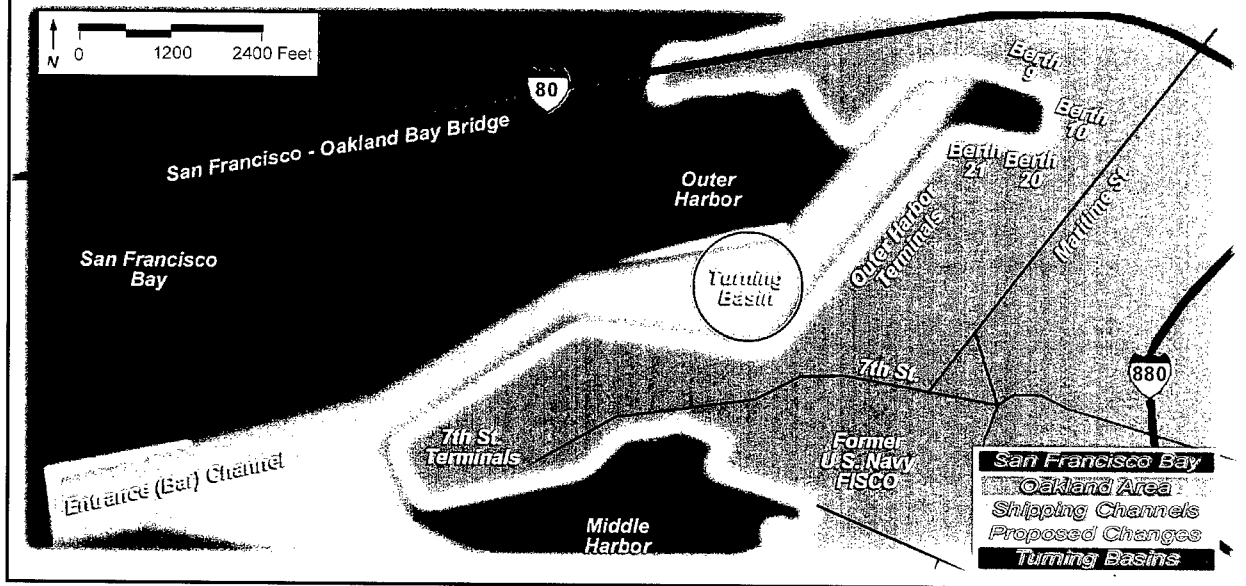


Figure 4. Oakland Harbor - possible Outer Harbor improvements

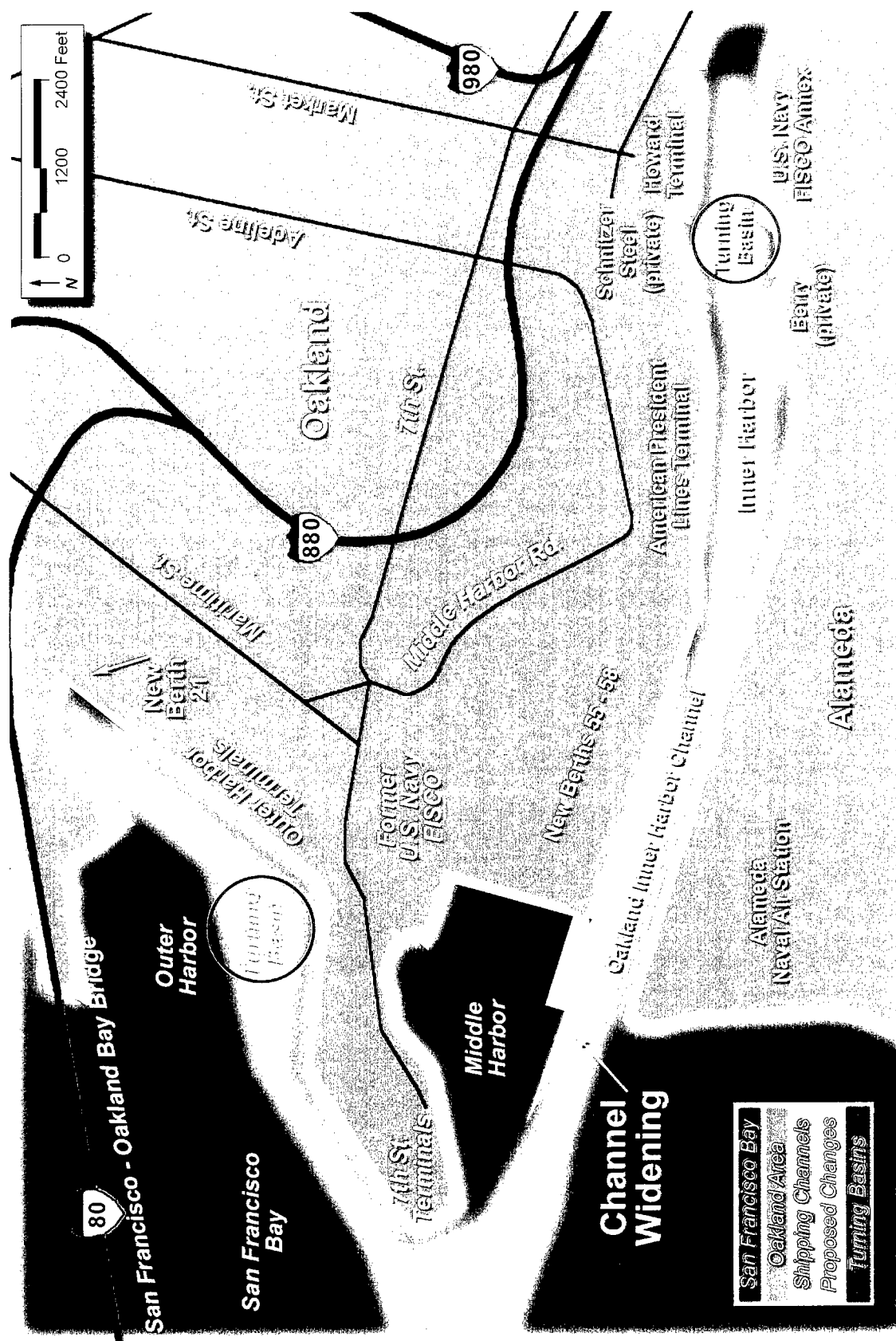


Figure 5. Oakland Harbor - possible Inner Harbor navigation improvements



Figure 6. Leonard Cardoza, Capt. Asmund Gjevik, and Gary Lynch (with video) onboard the President Polk



Figure 7. Oakland Harbor - Taking 35mm photos onboard the President Polk containership

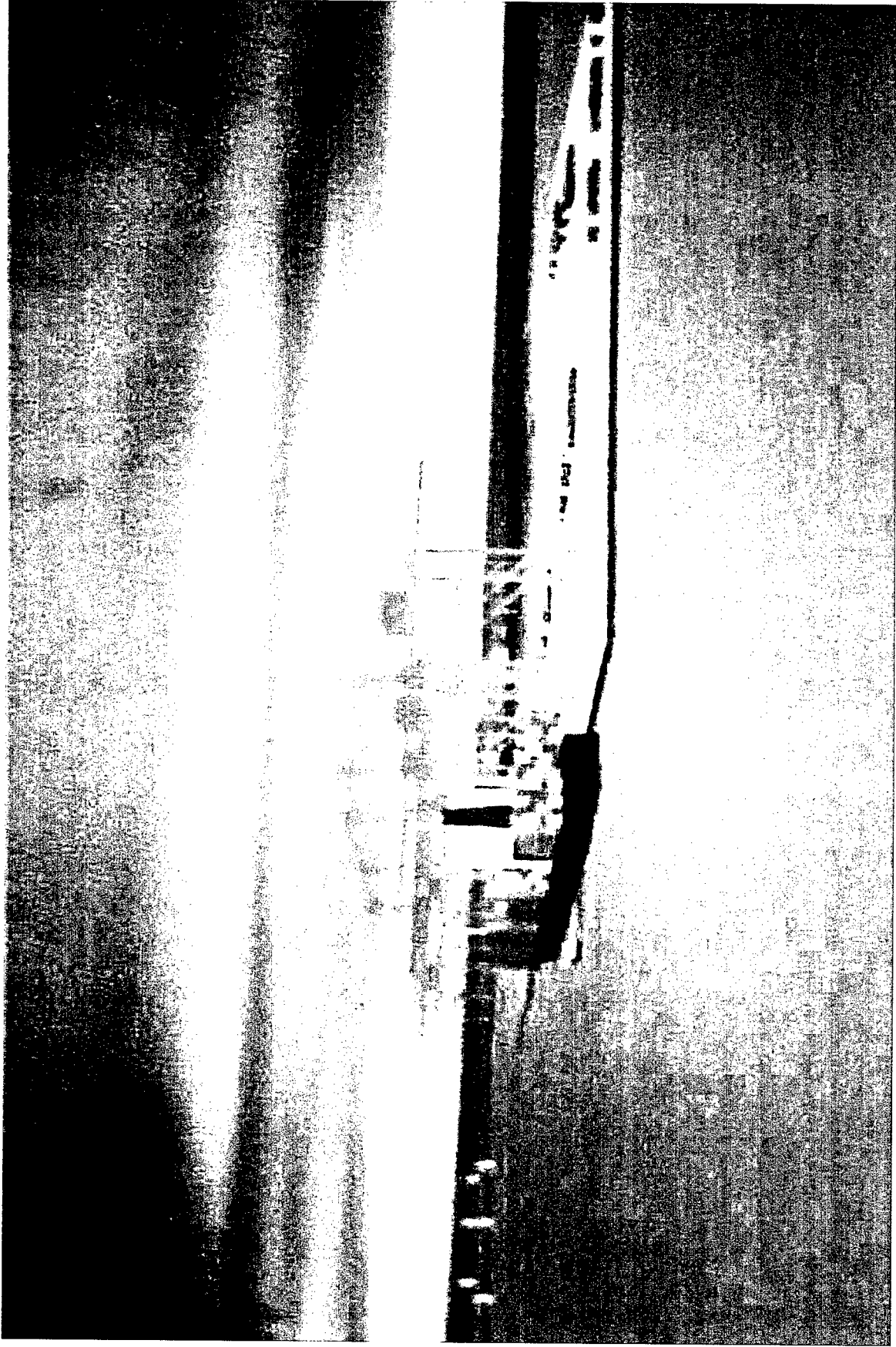


Figure 8. Generalized containership terminal from Oakland Harbor Navigation Study

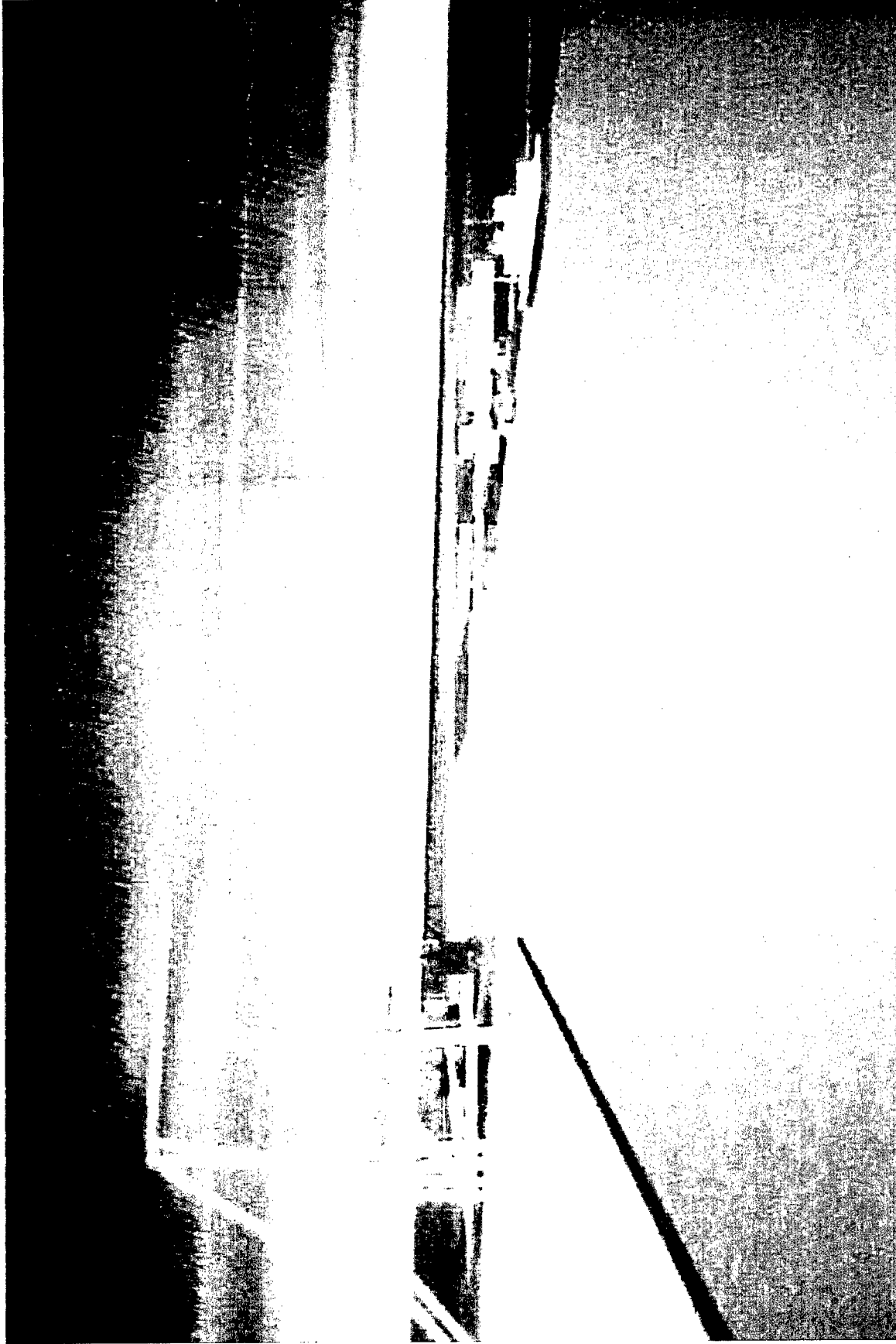


Figure 9. Simulator visual of Inner Harbor for Oakland Harbor Navigation Study

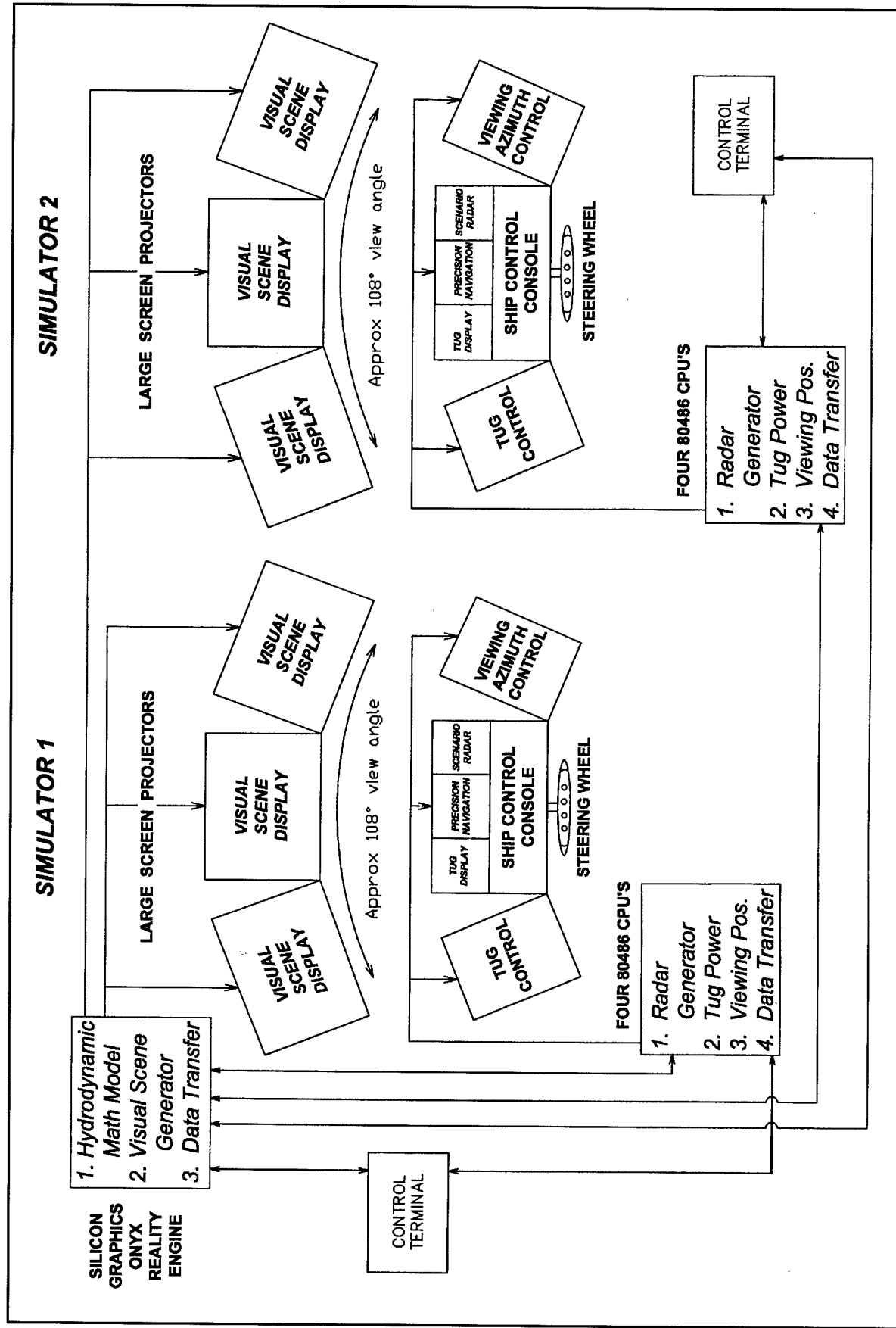


Figure 10. ERDC Coastal and Hydraulics Laboratory - ship/tow simulator setup

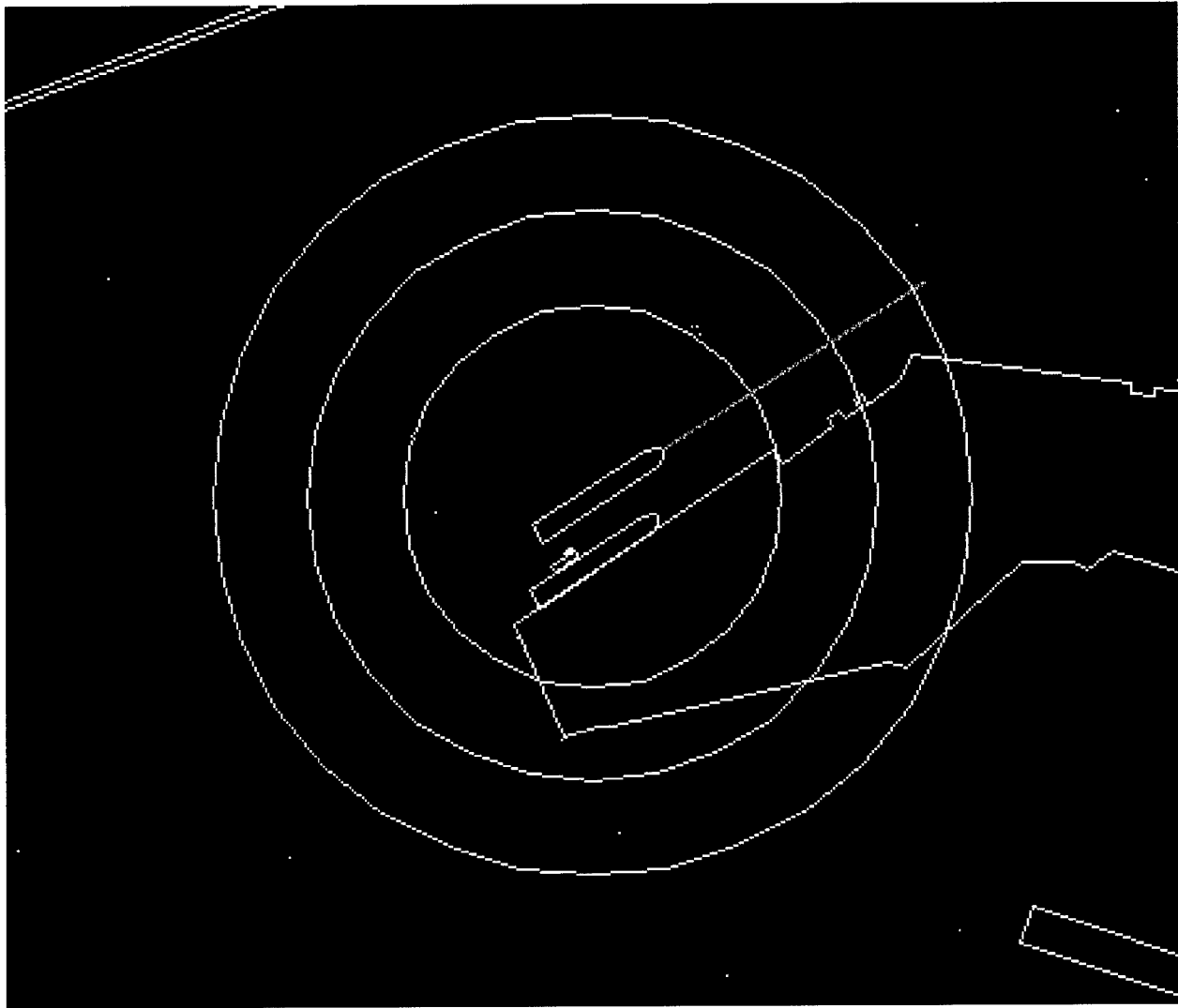


Figure 11. Ship/tow simulator radar screen

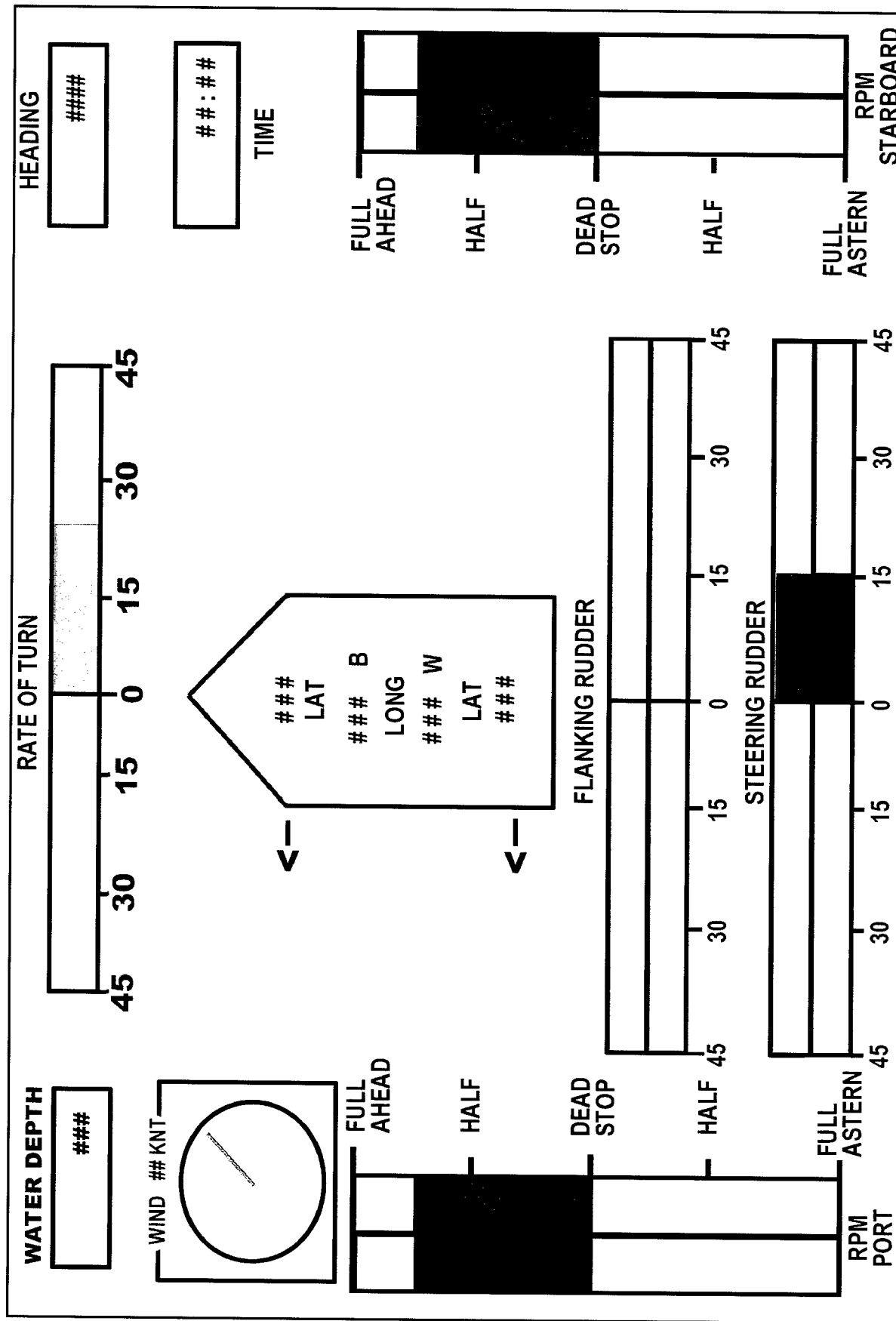


Figure 12. Navigation parameters screen

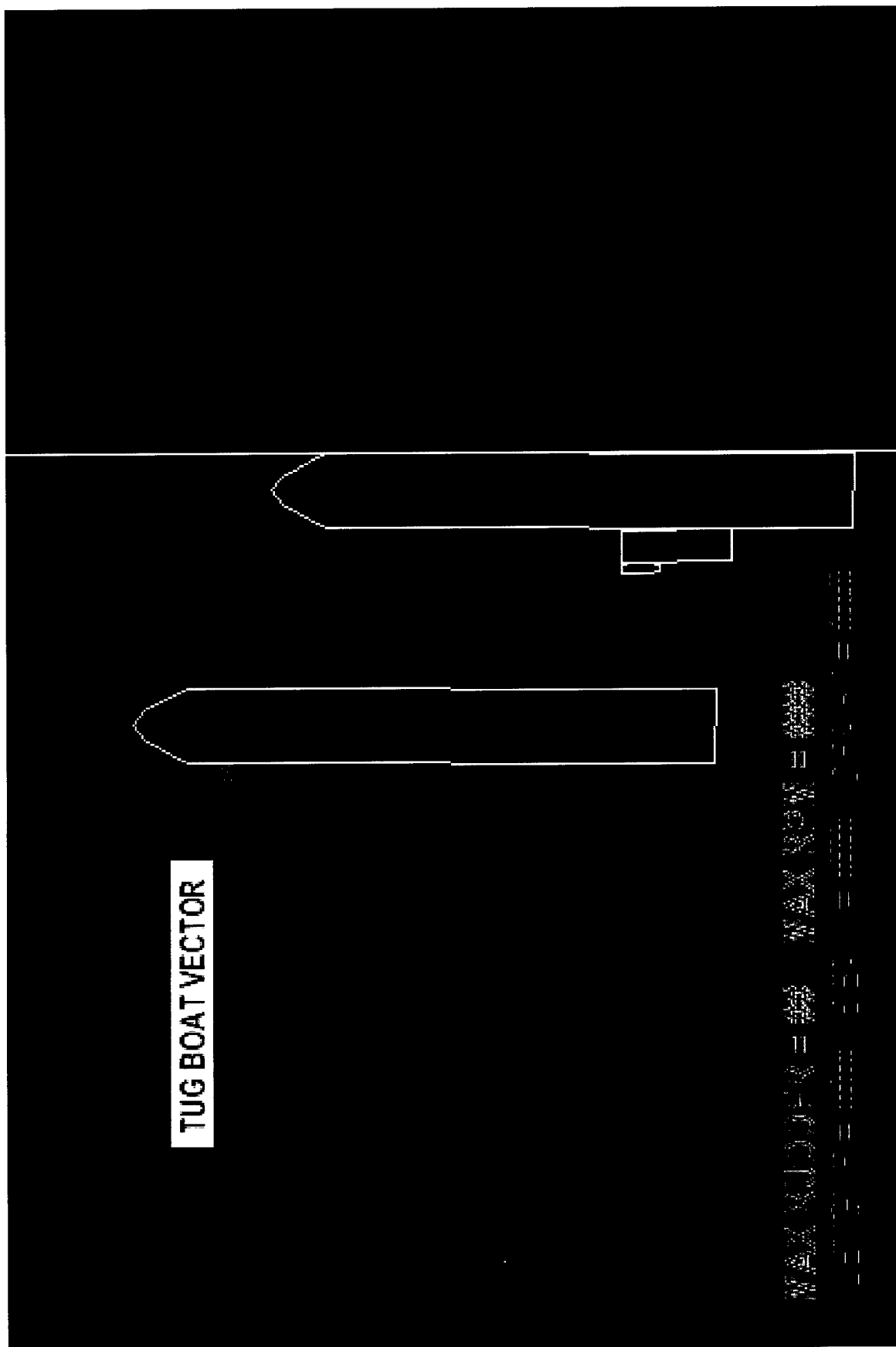


Figure 13. Ship/tow simulator fixed-range radar screen

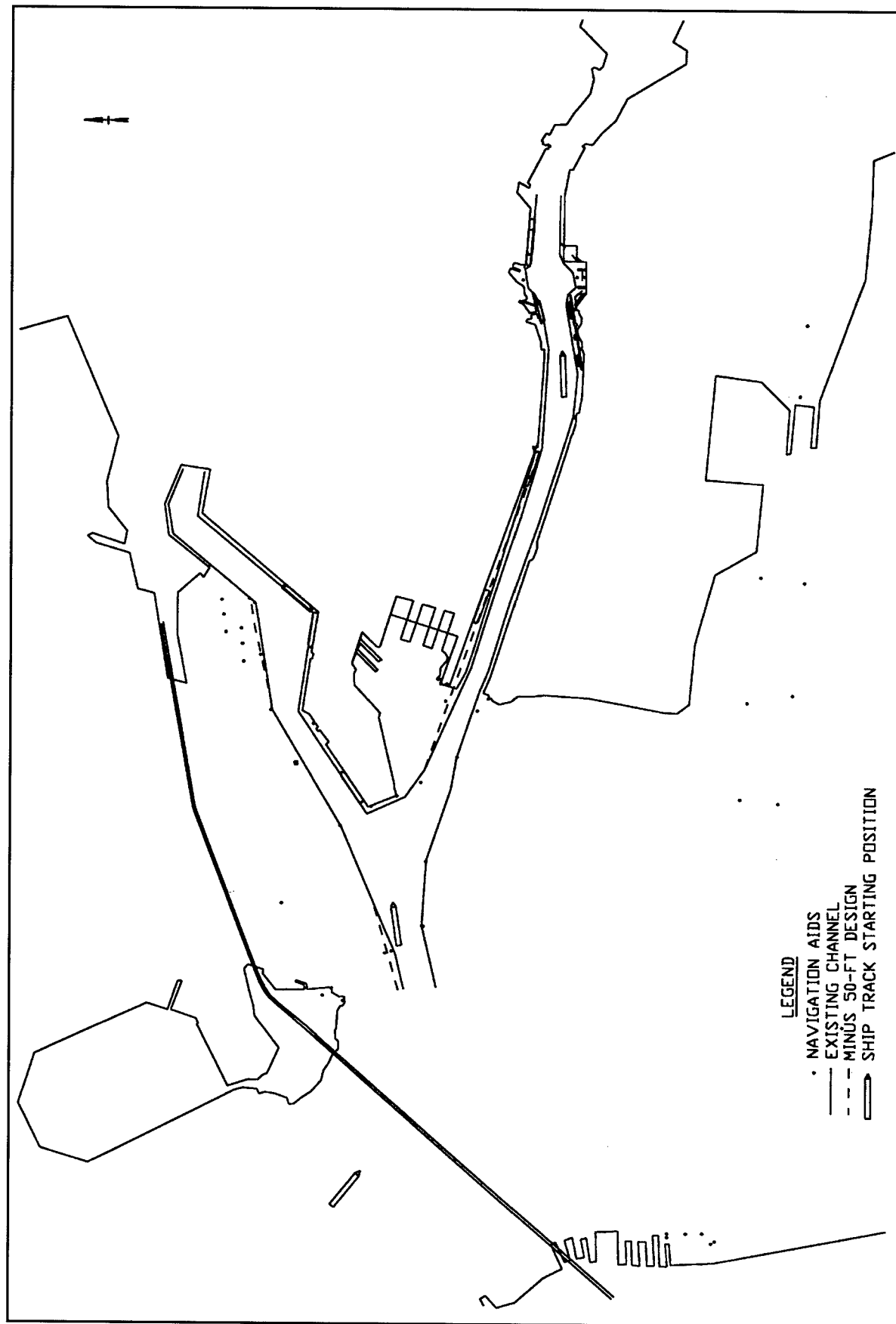


Figure 14. Initial starting positions for Oakland Harbor Navigation Study

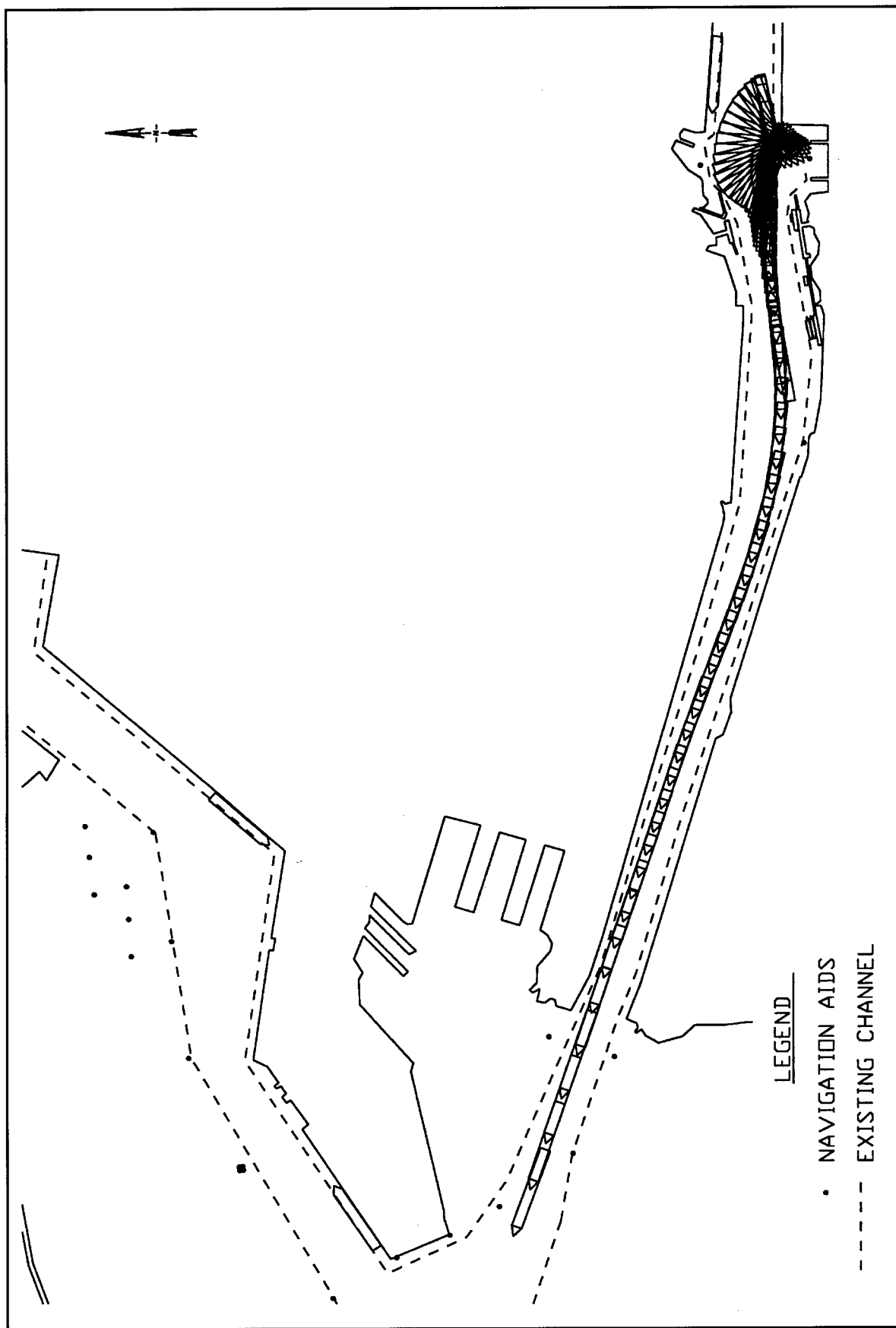
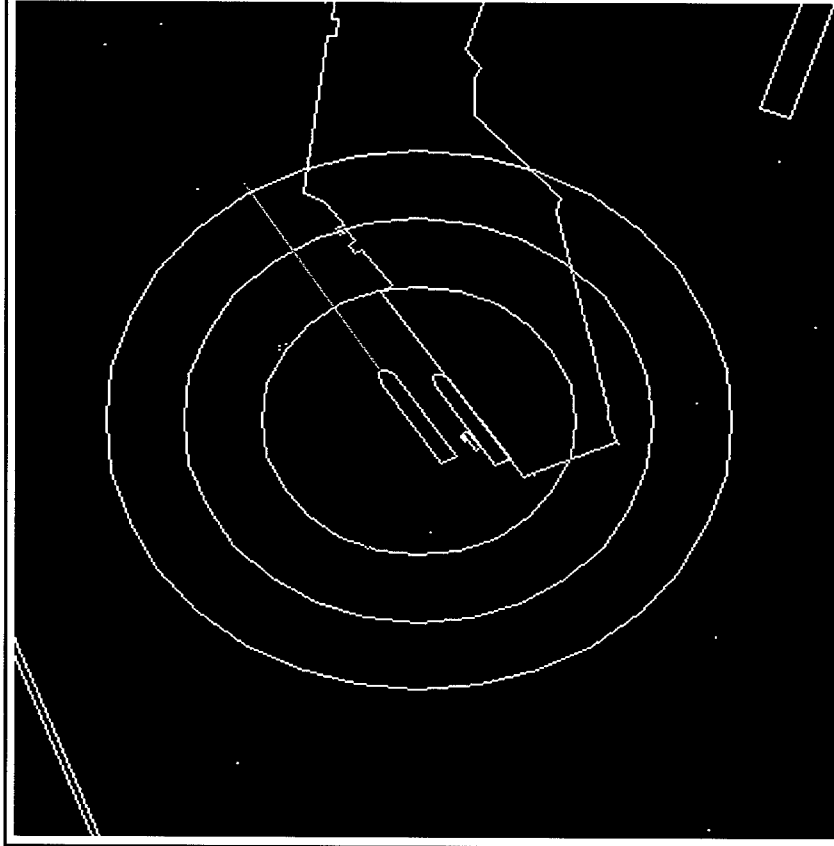


Figure 15. Example of track plot for Oakland Harbor Navigation Study



Simulation Radar Screen



Sample of Possible Radar Screen

Figure 16. Comparison of radar images

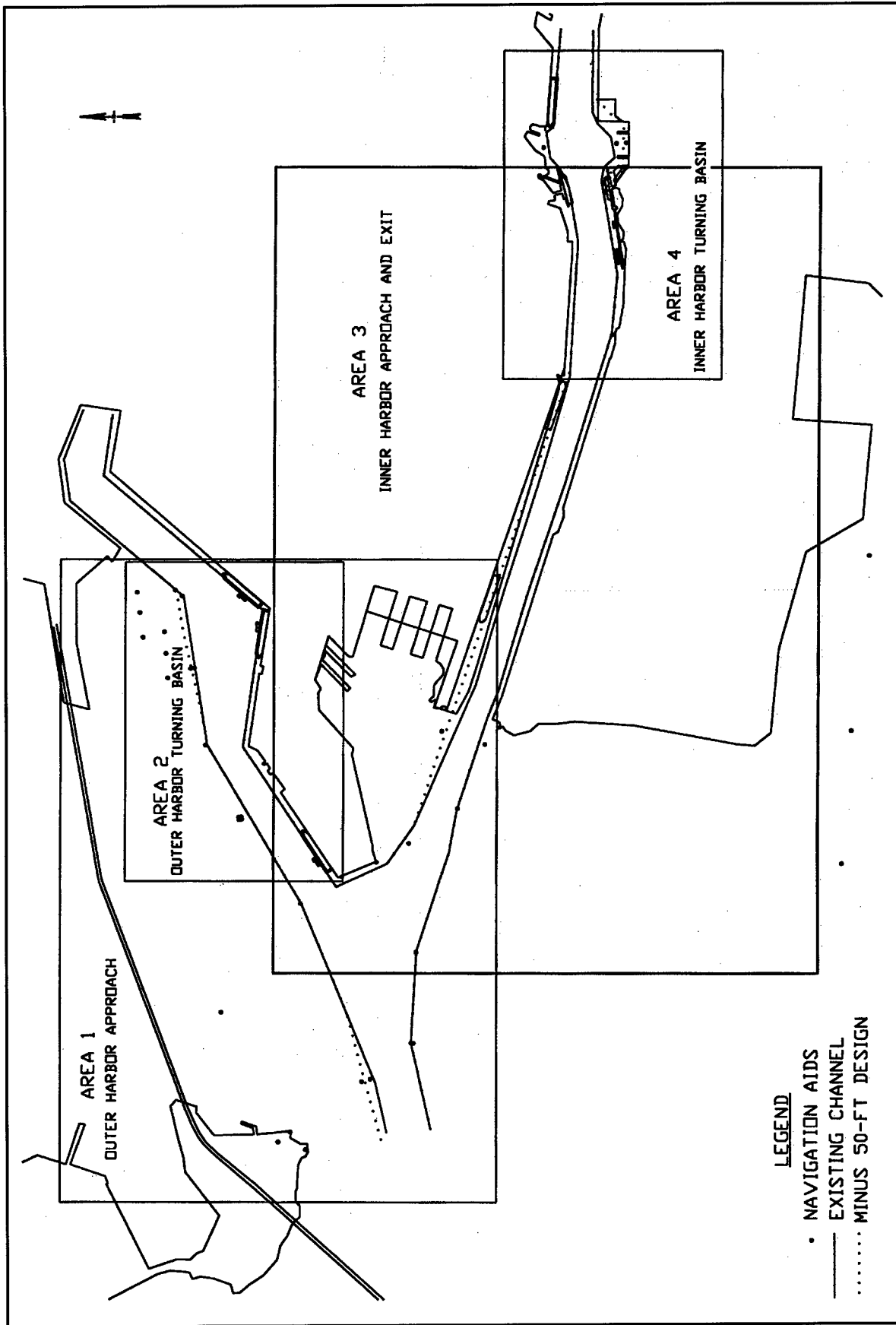


Figure 17. Oakland Harbor Navigation Study track plot areas

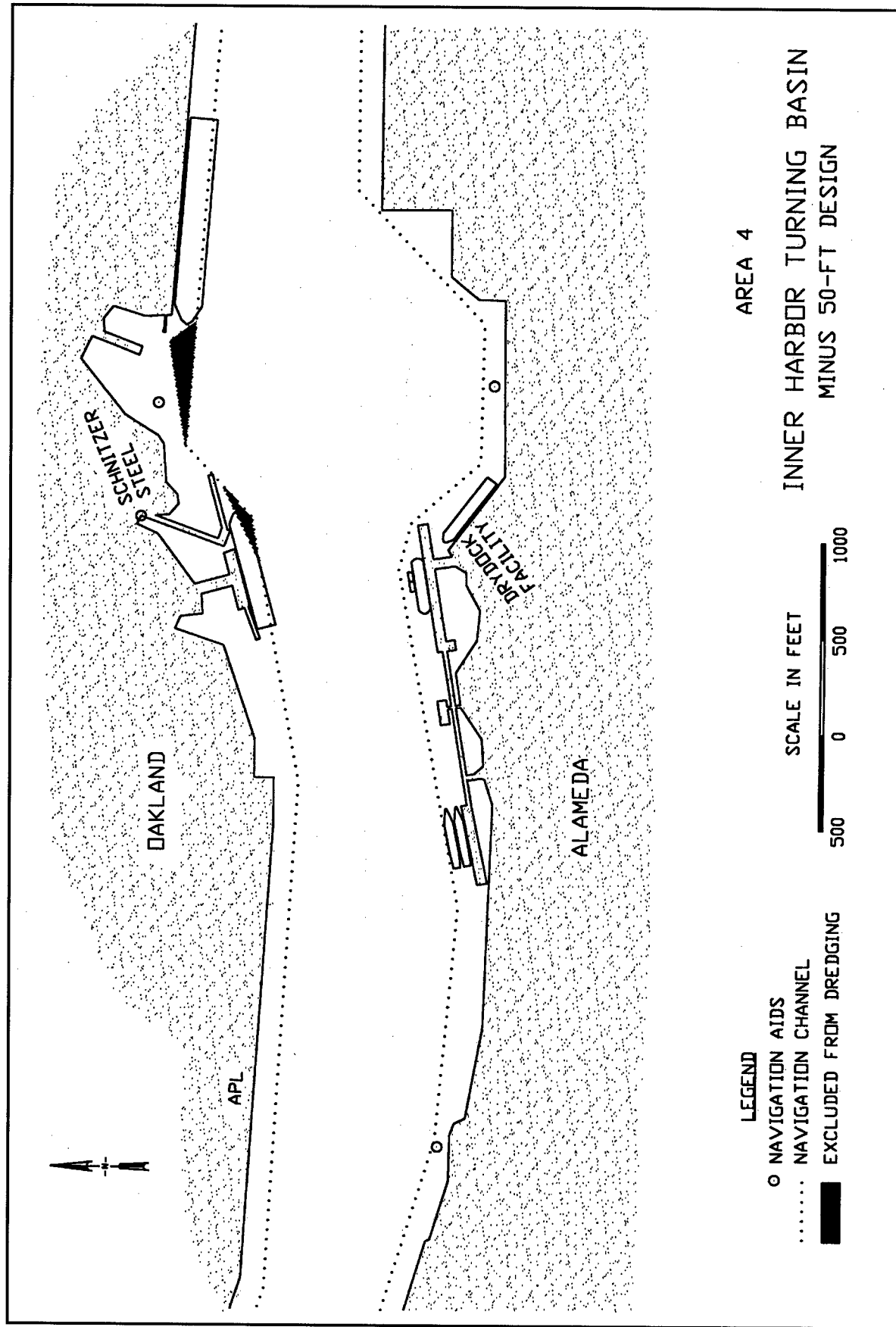


Figure 18. Minus 50 ft port design for Inner Harbor turning basin showing excluded sections

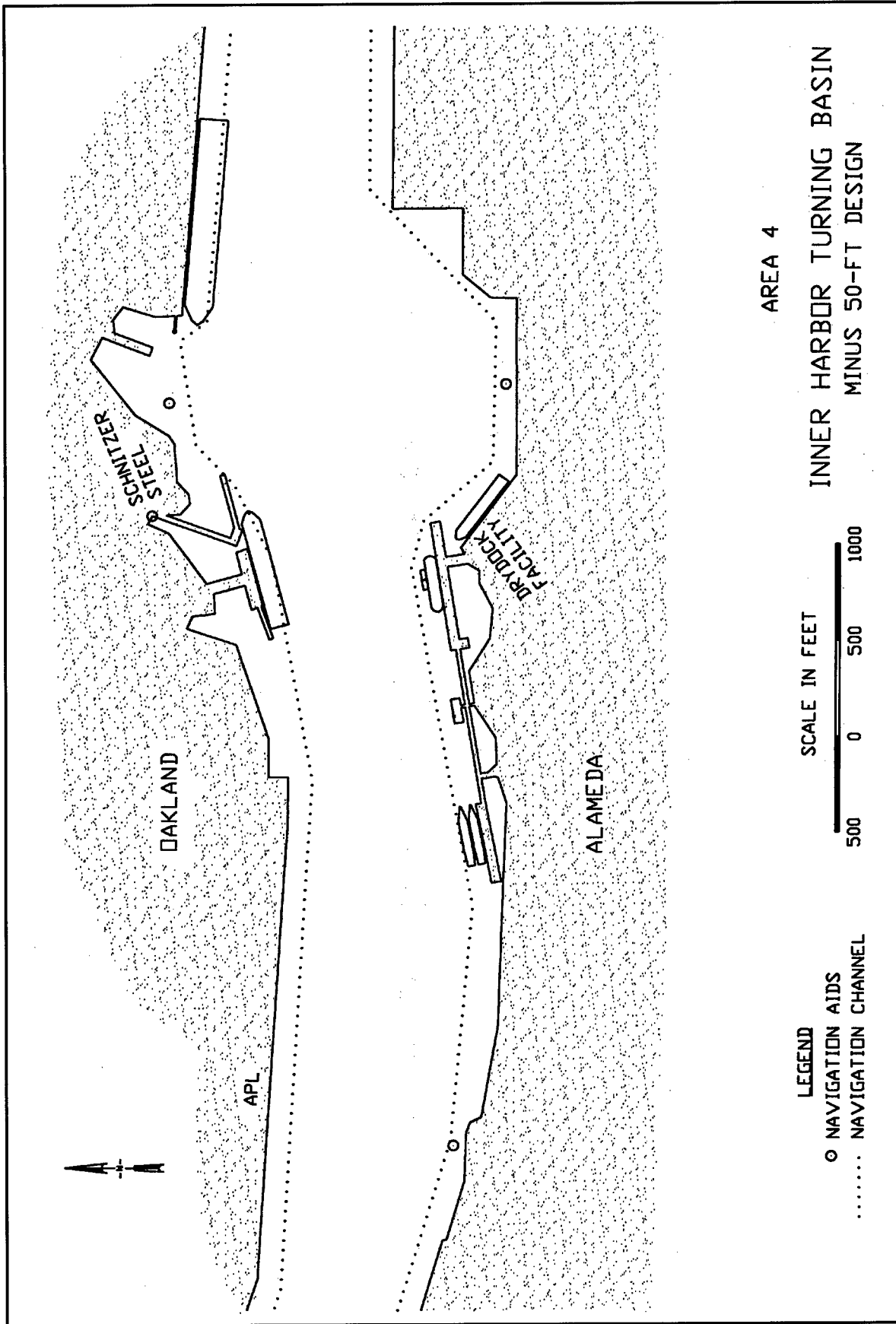
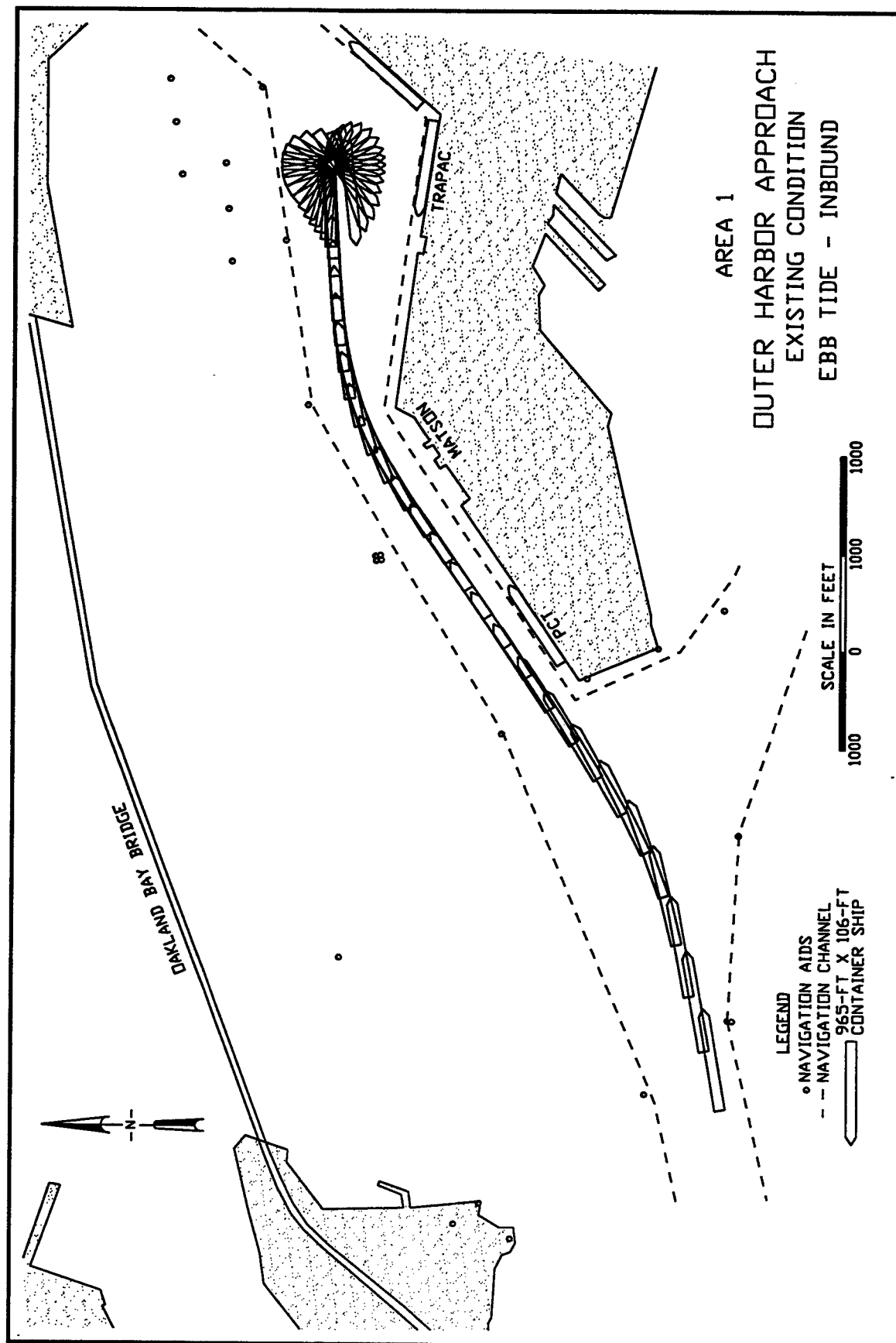
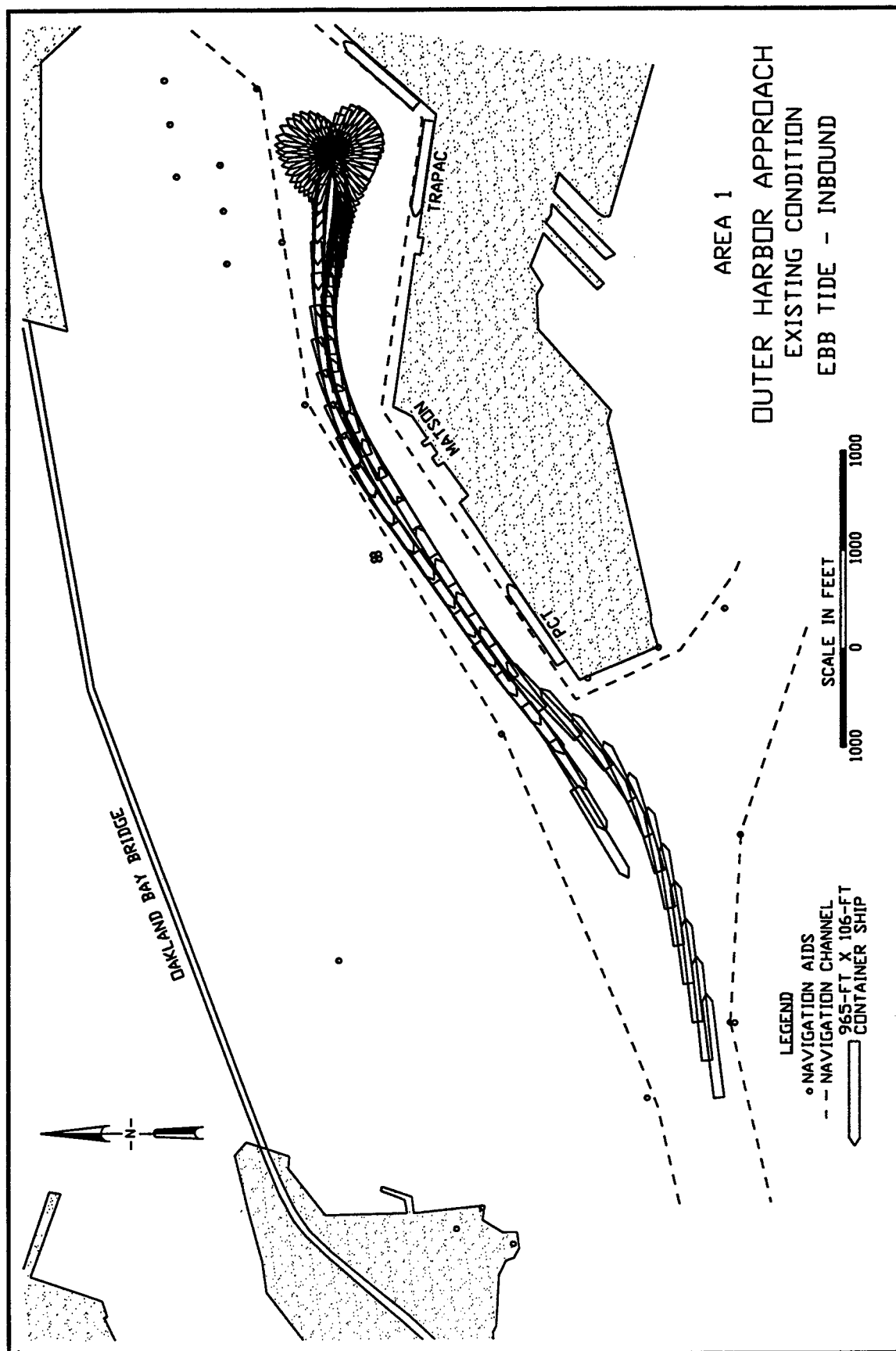
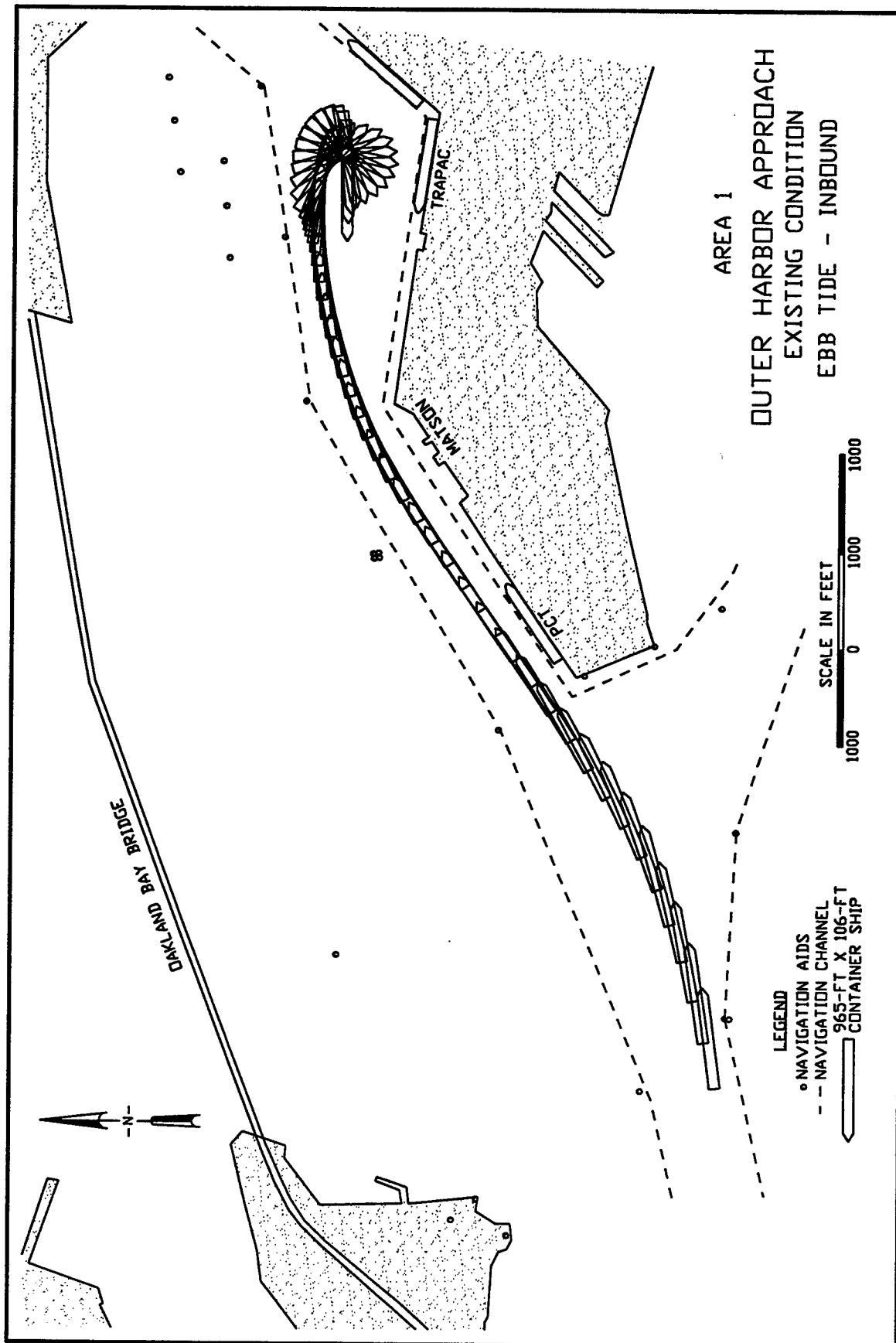


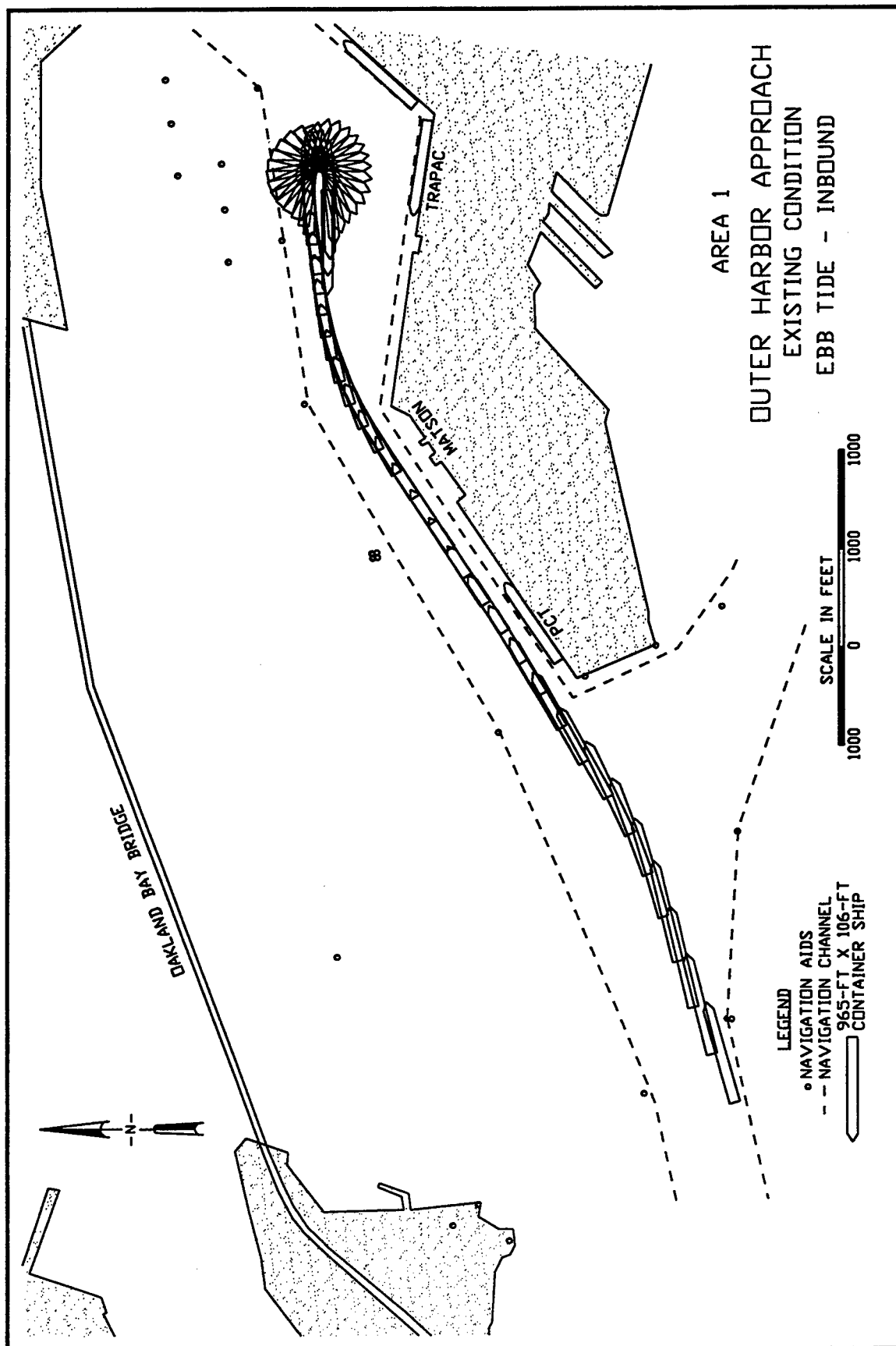
Figure 19. Recommended design for Inner Harbor turning basin, Oakland Harbor Navigation Study

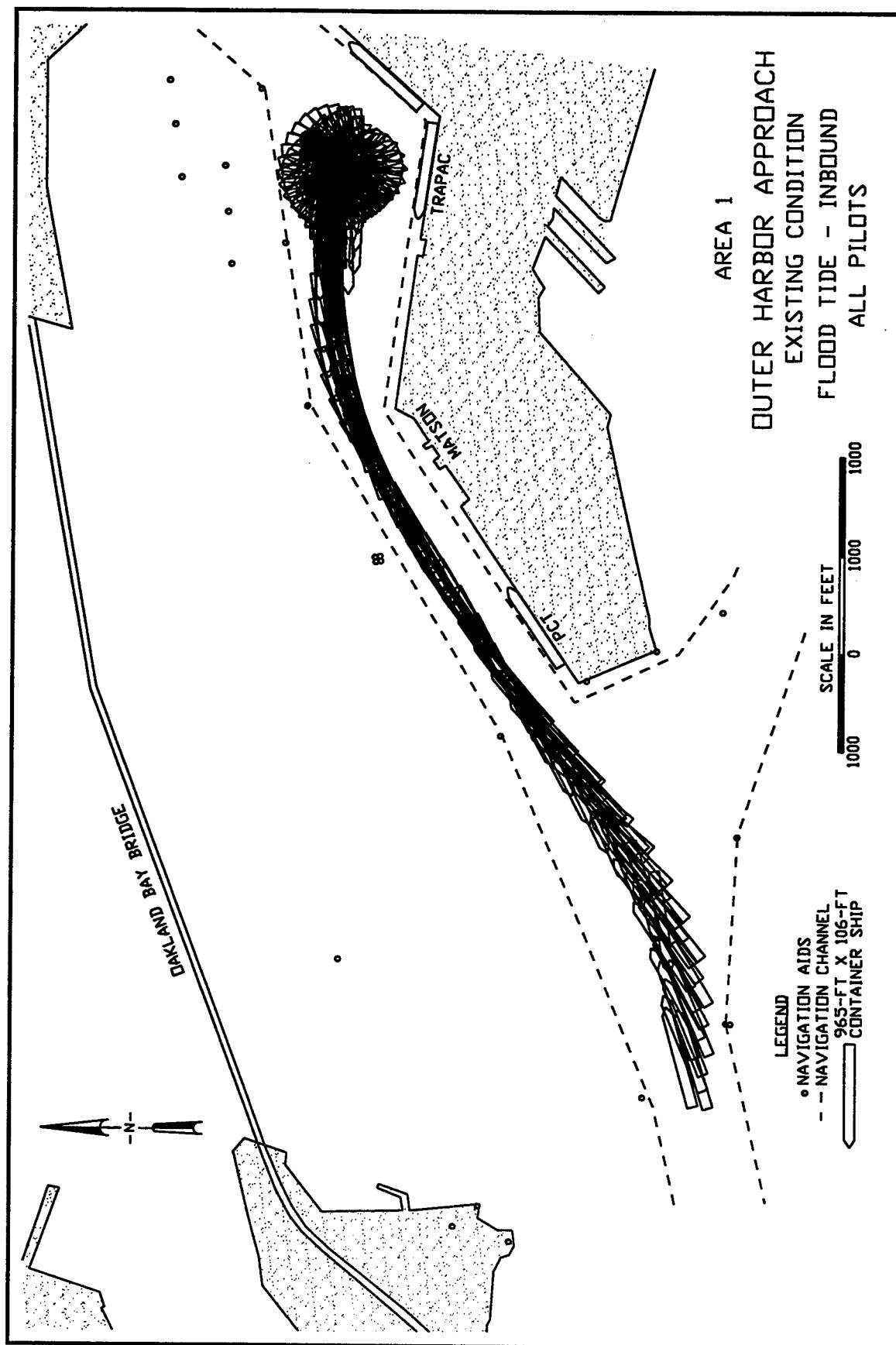


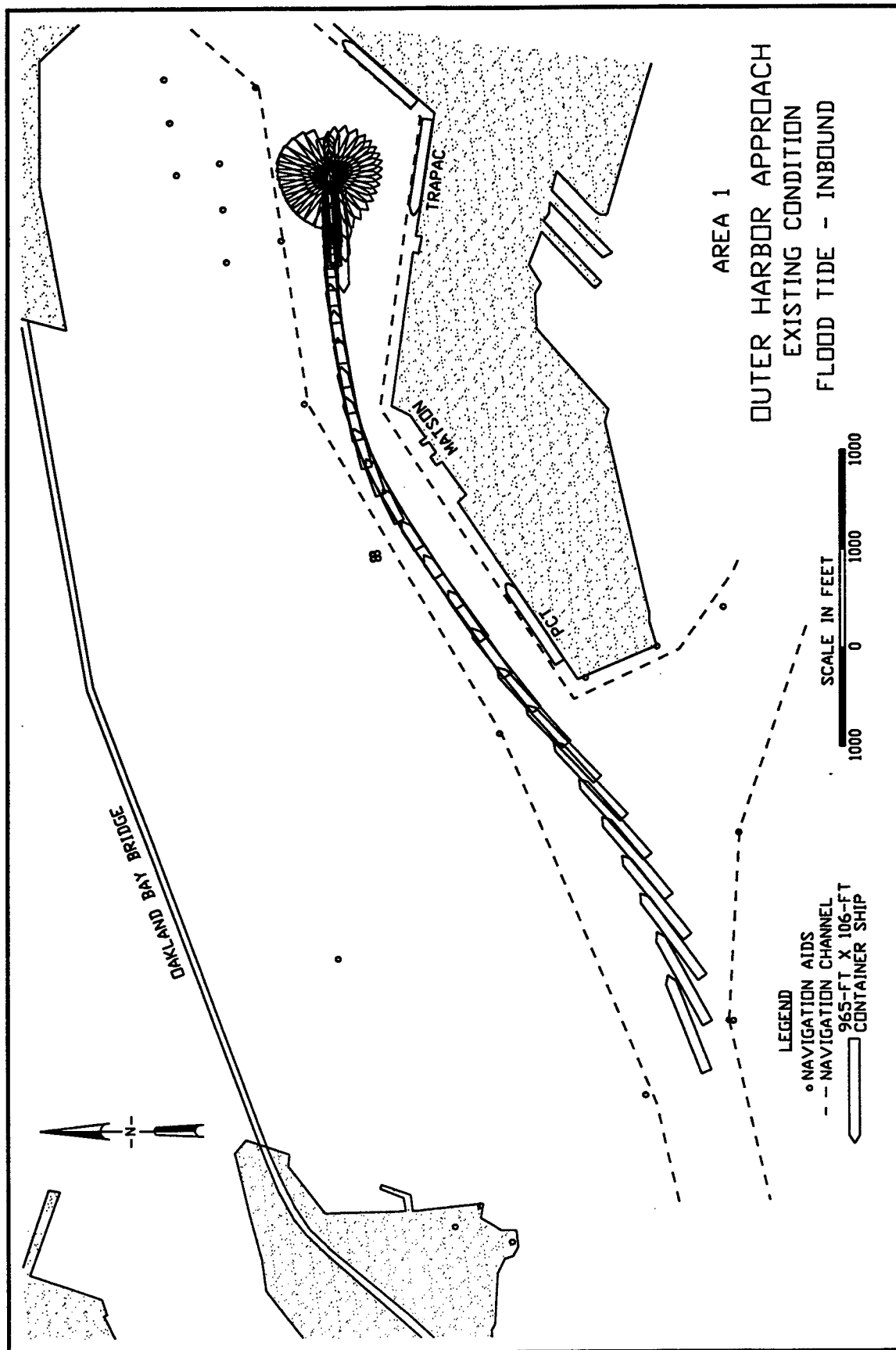


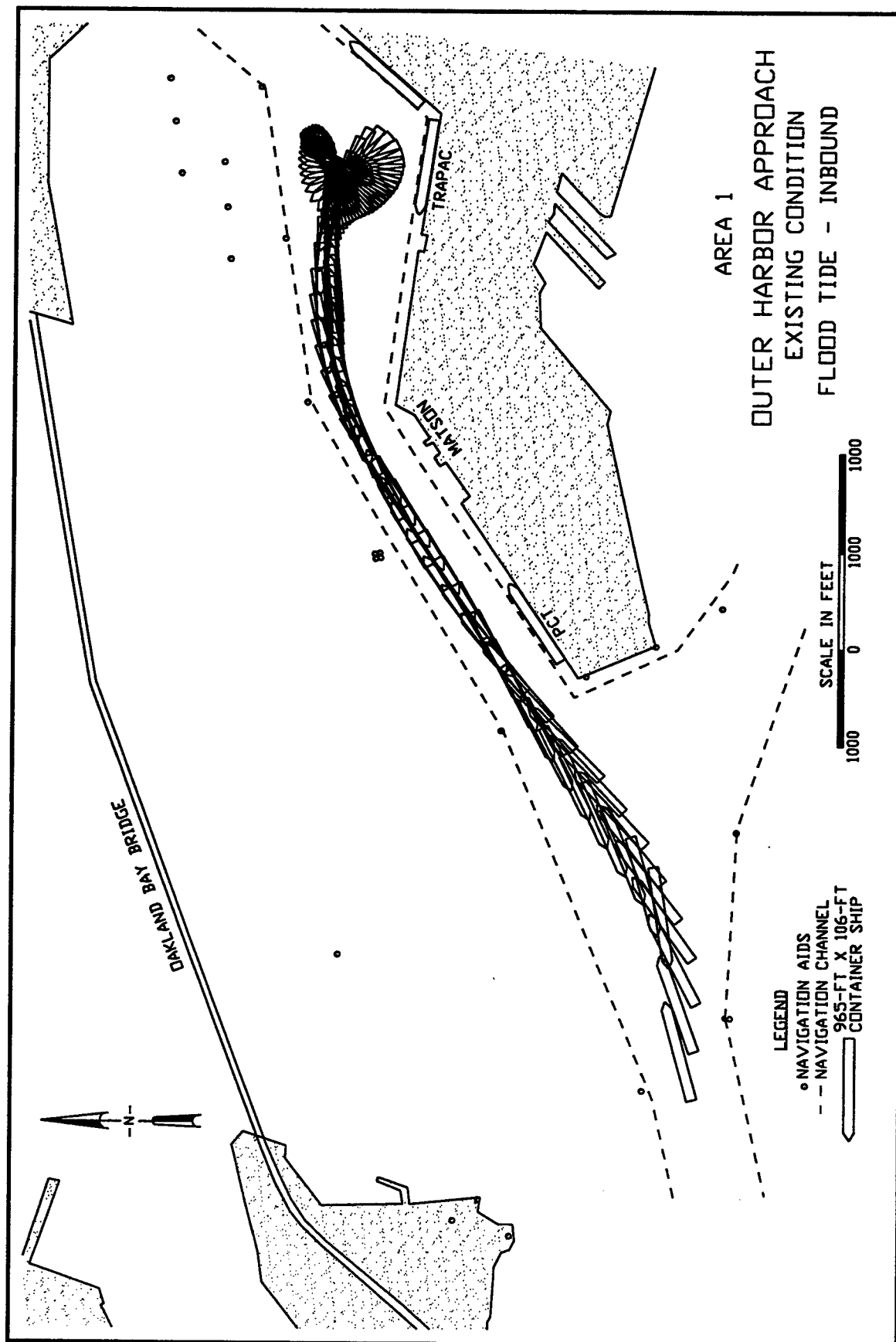


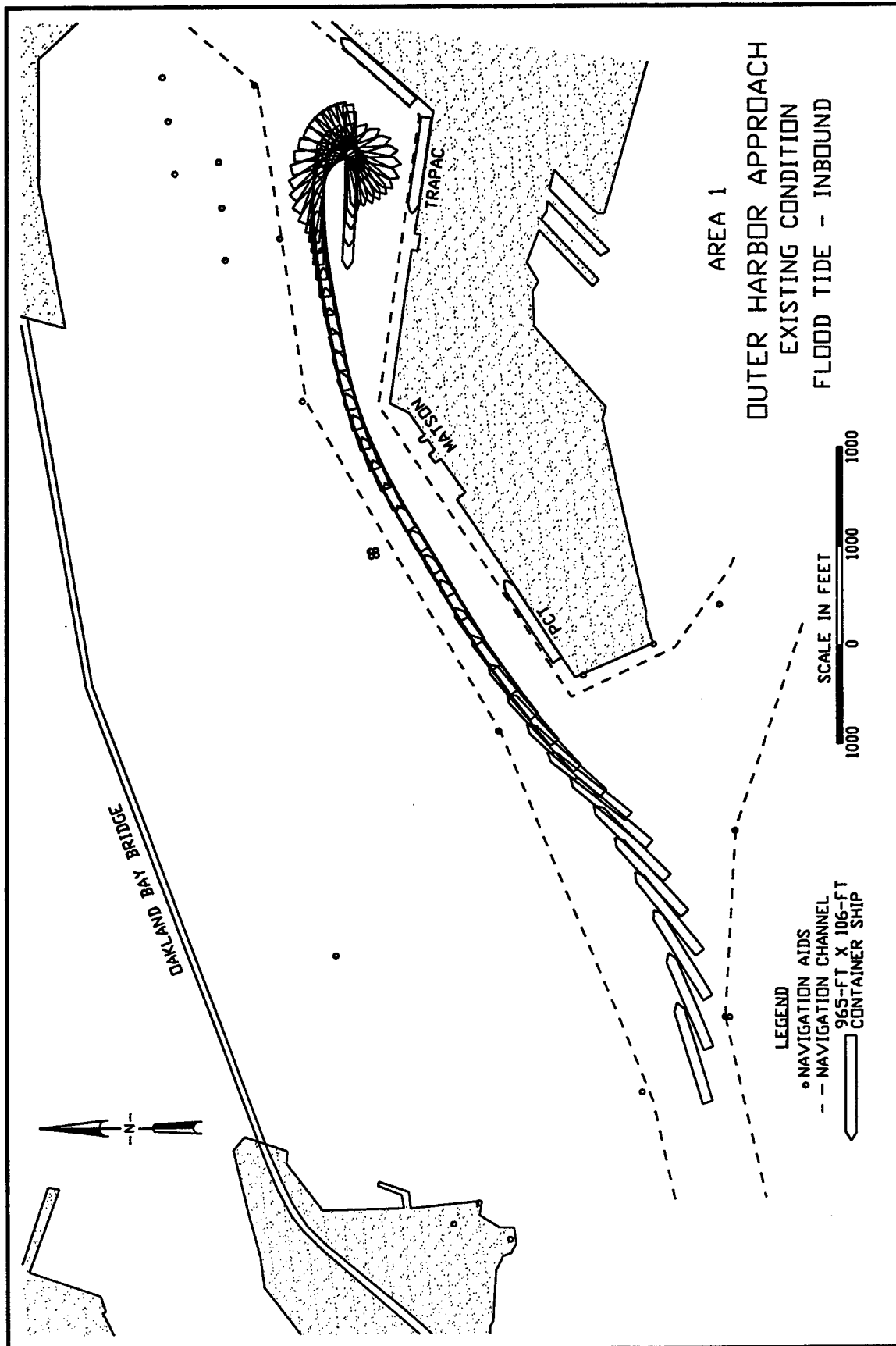












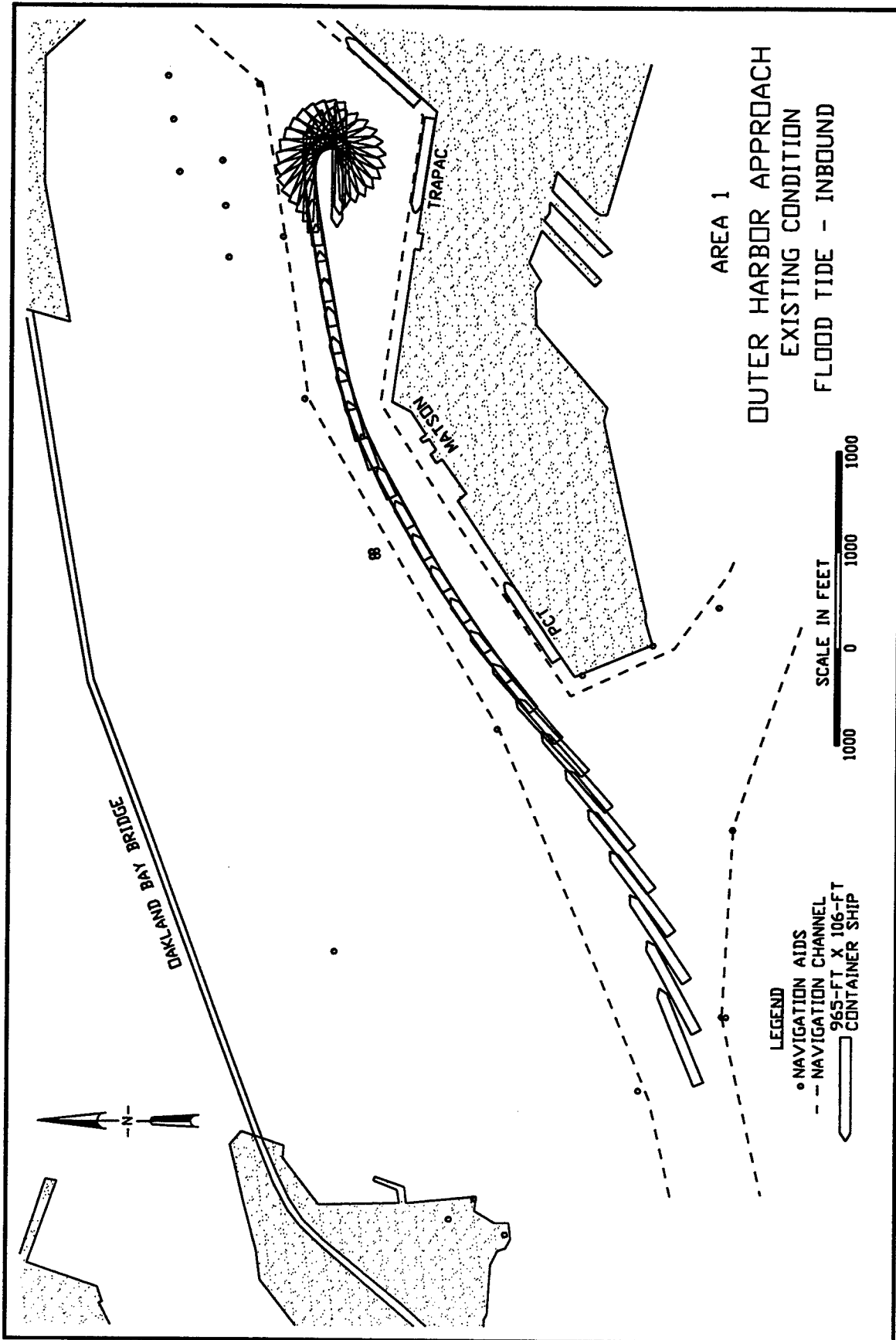
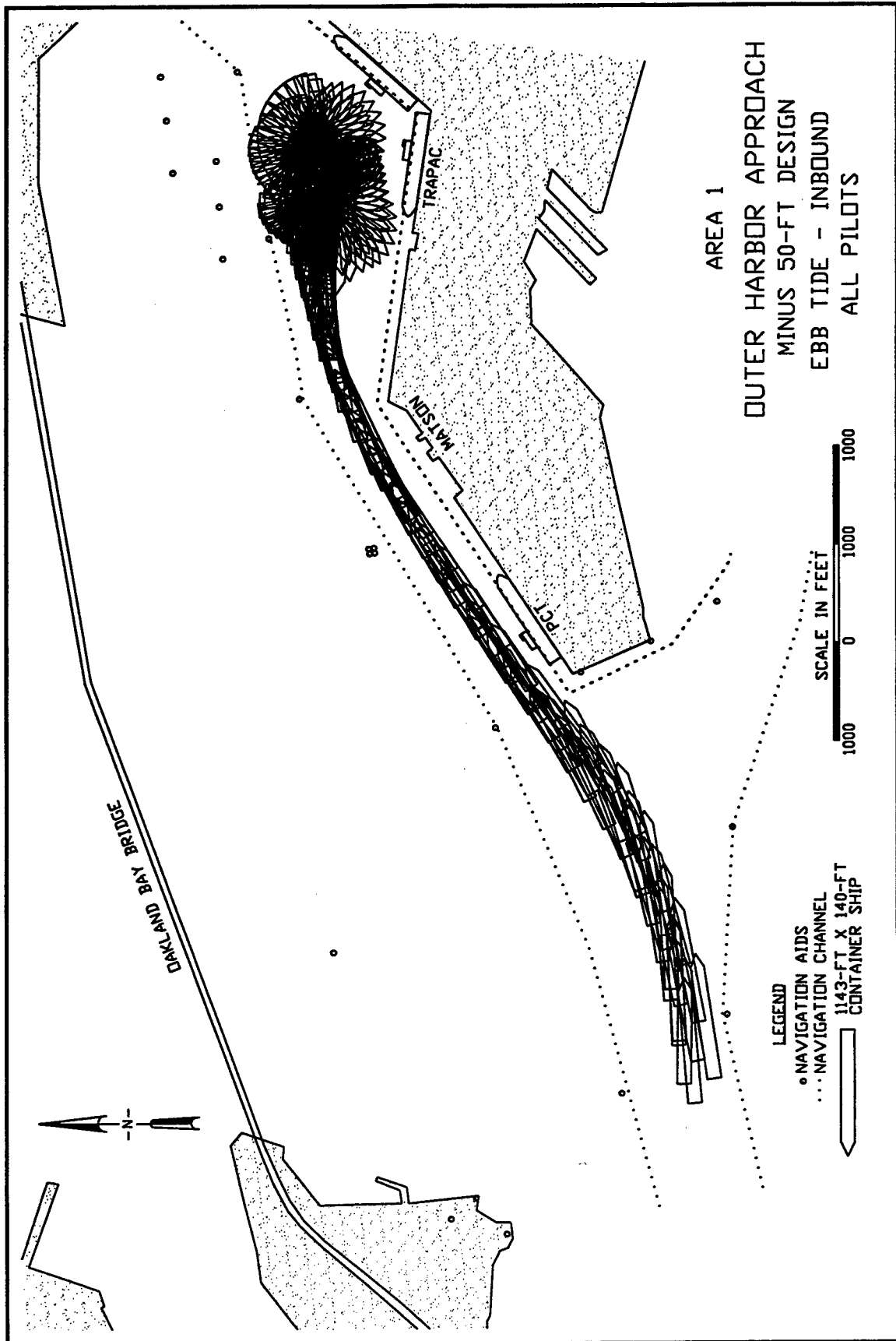
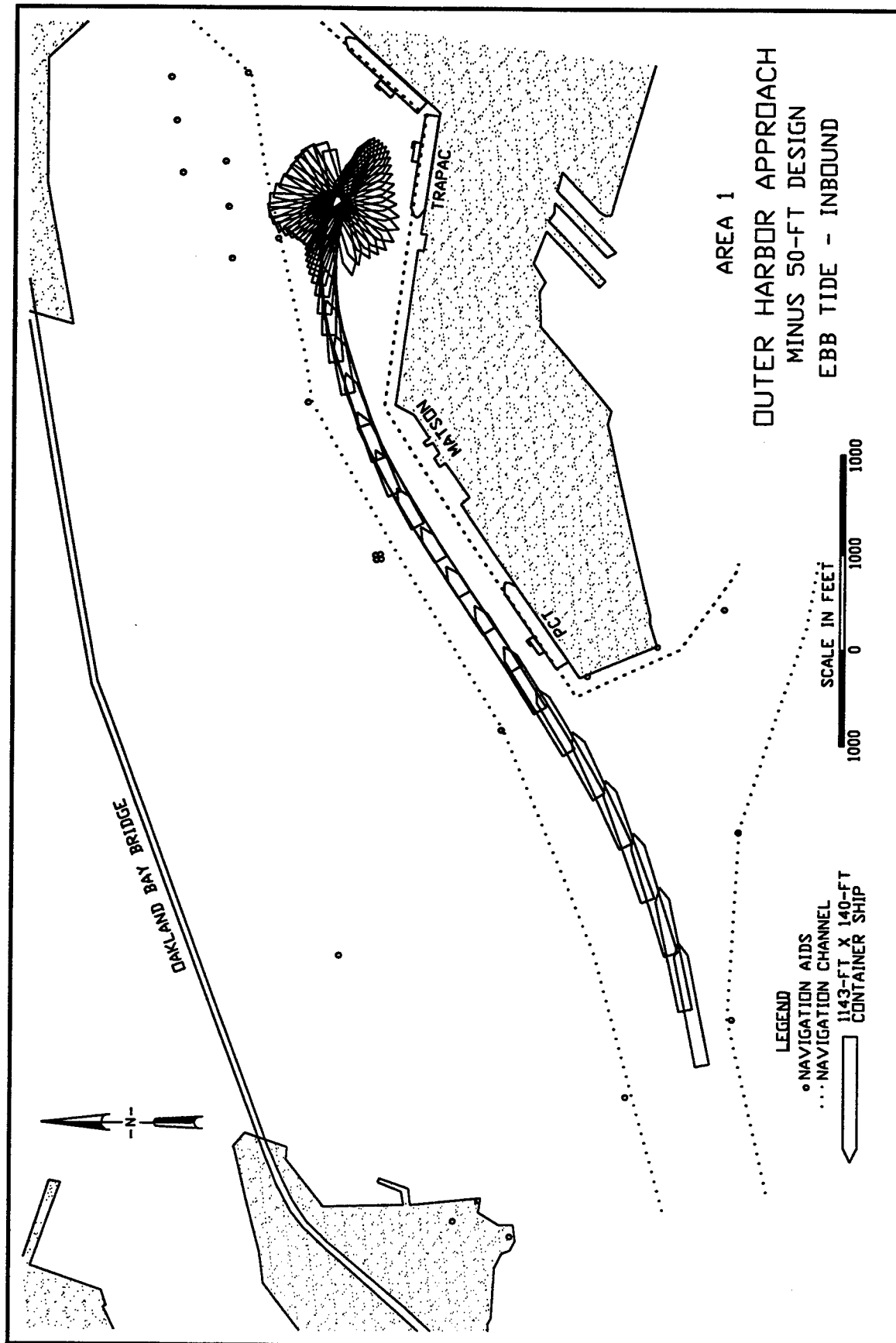
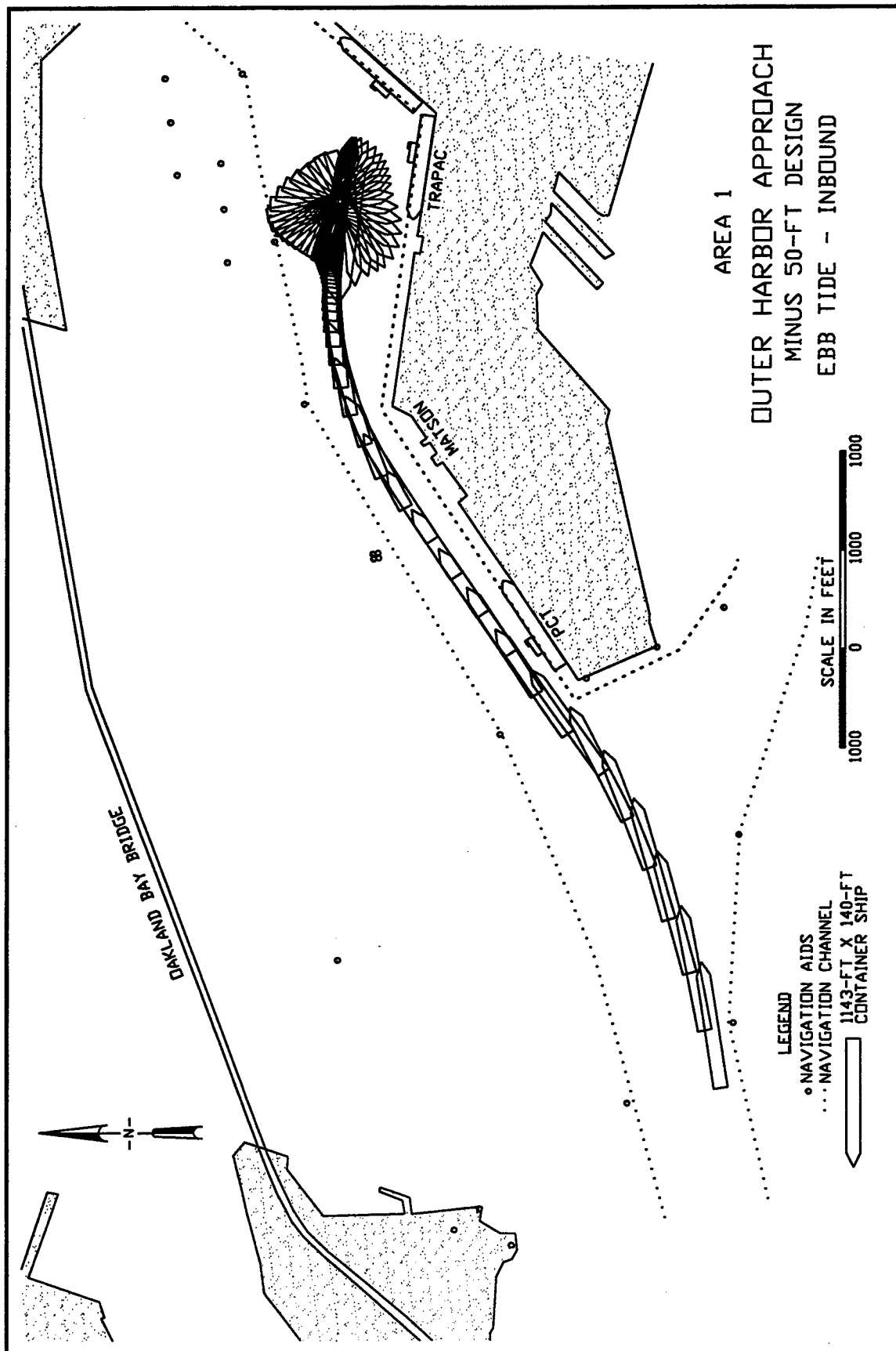
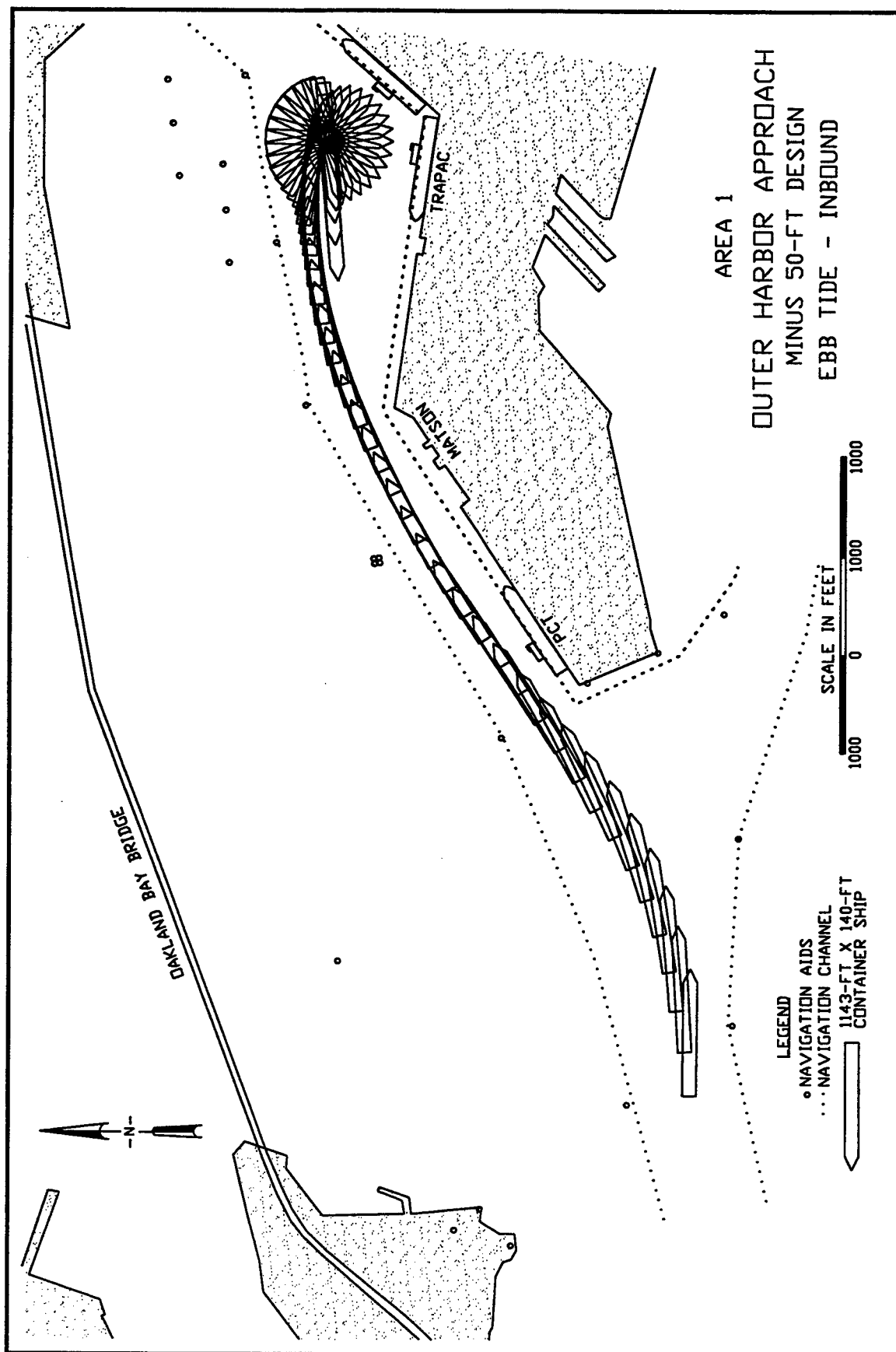


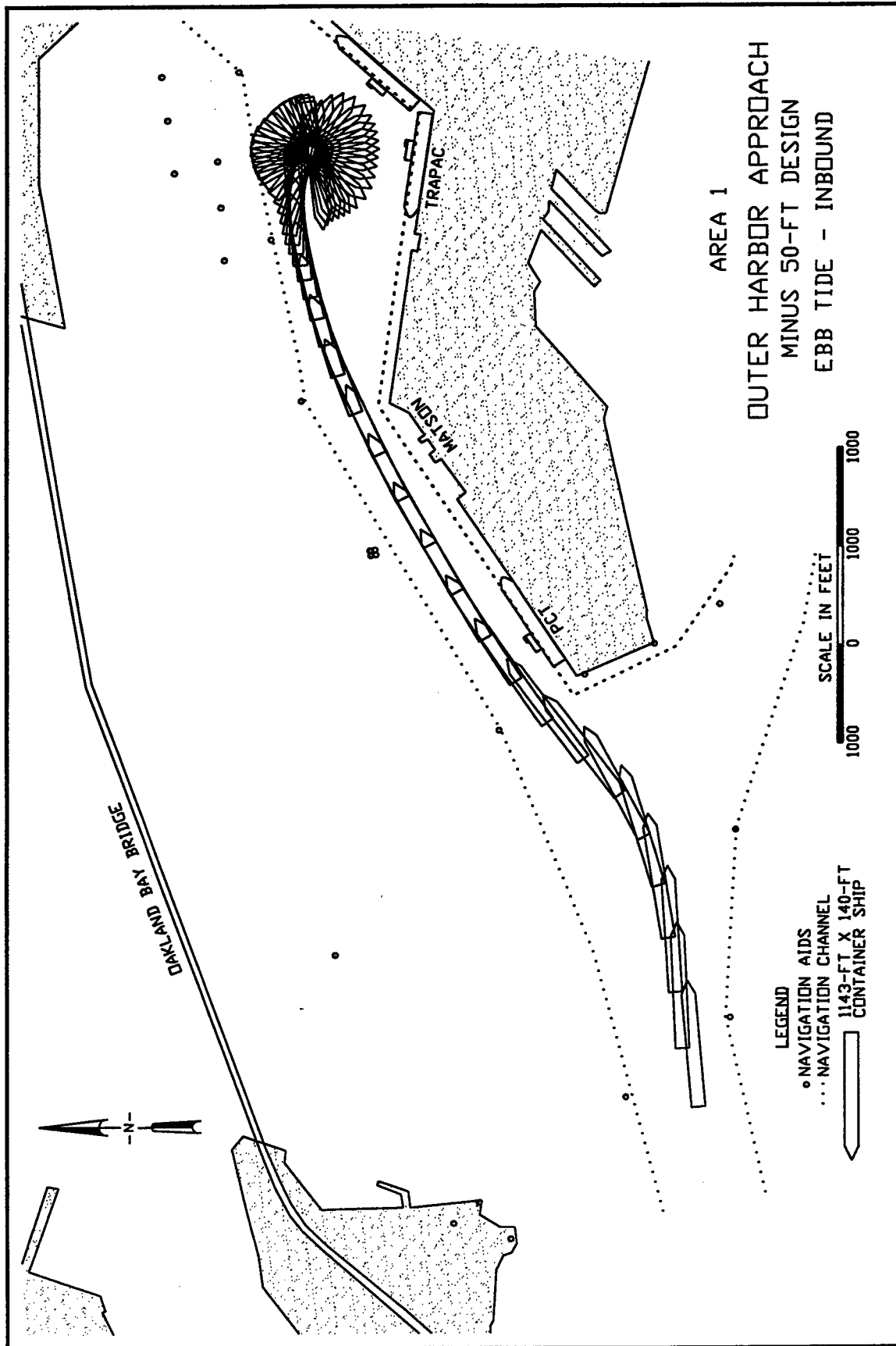
PLATE 10



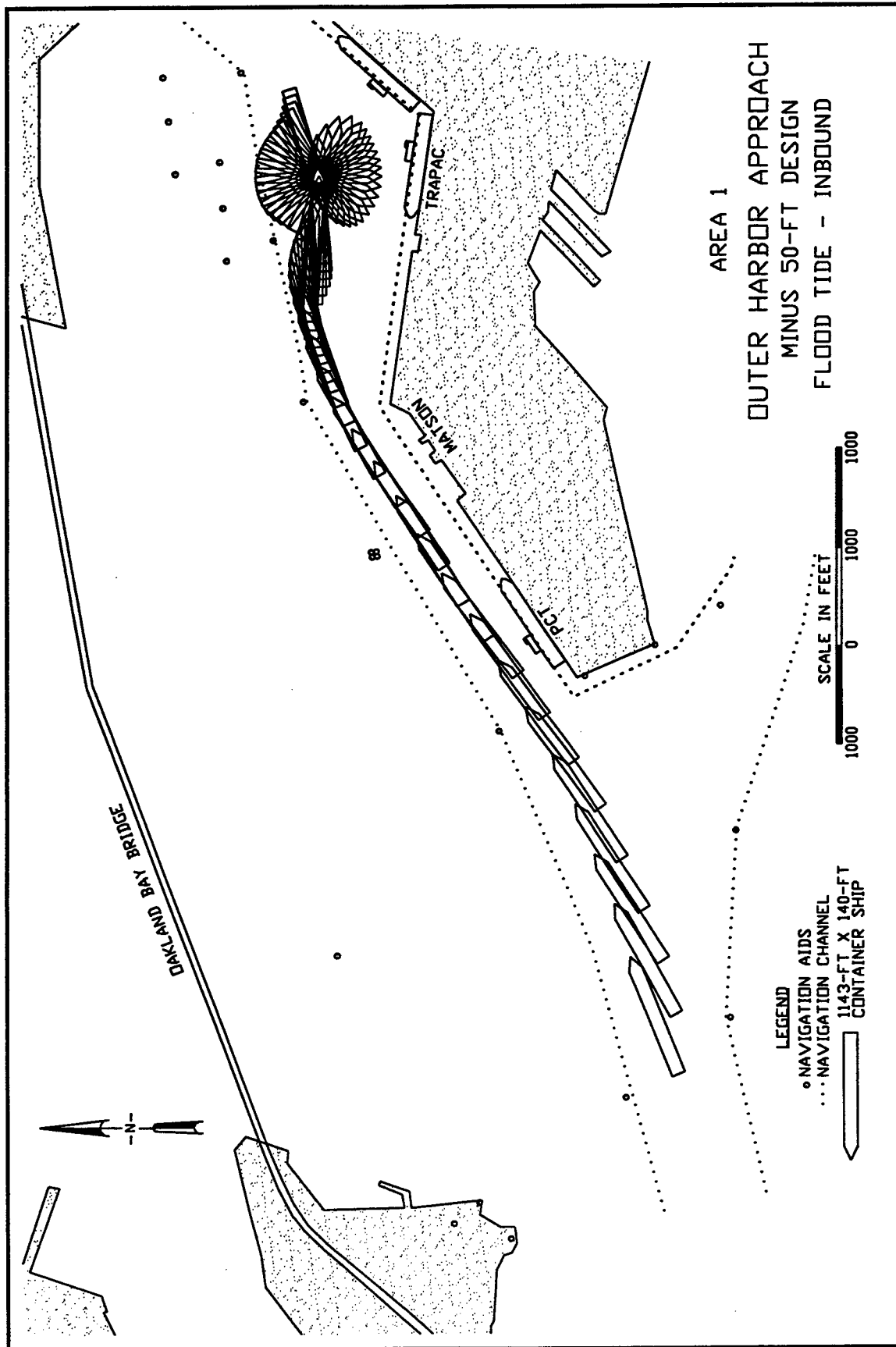


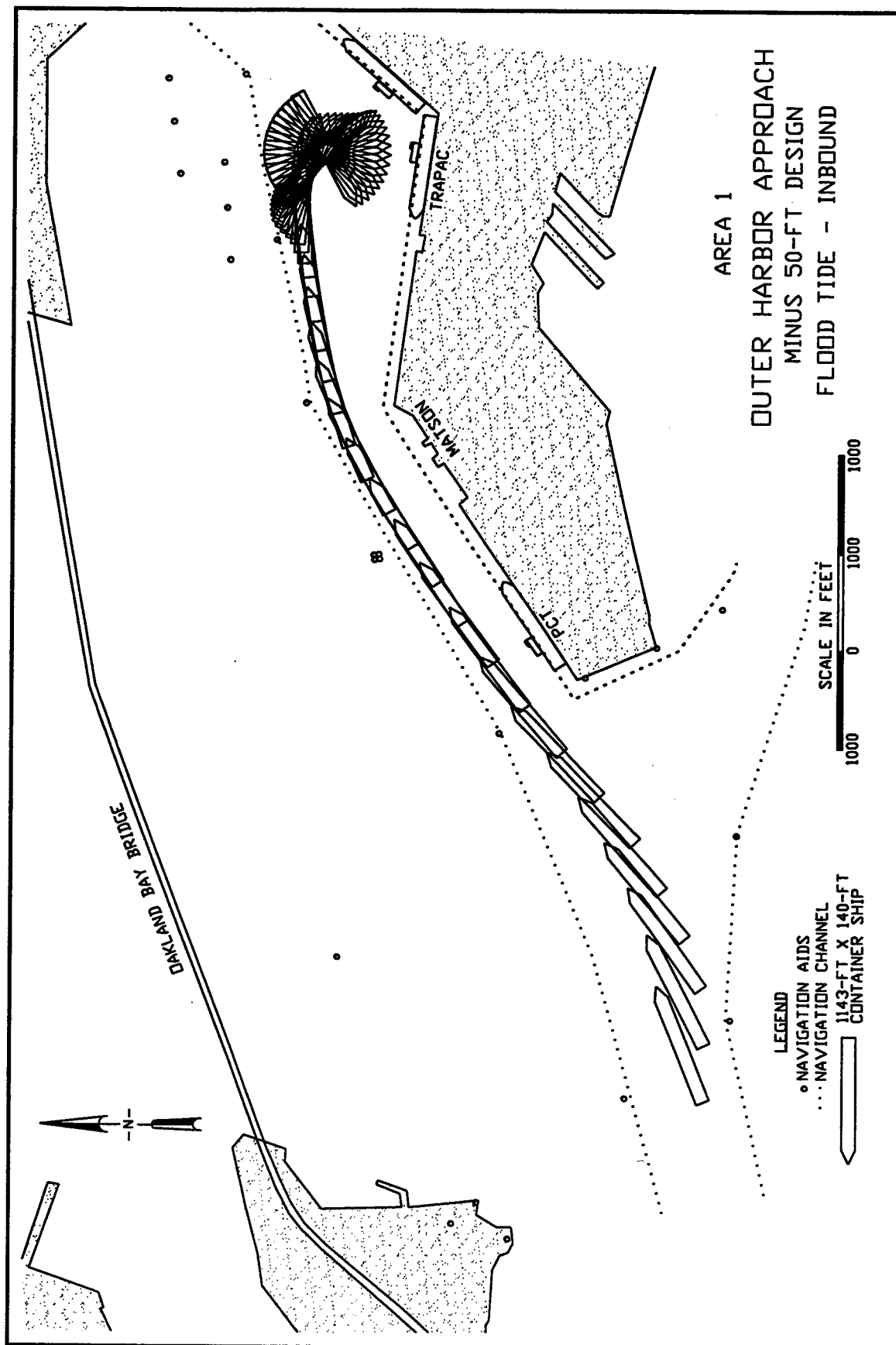


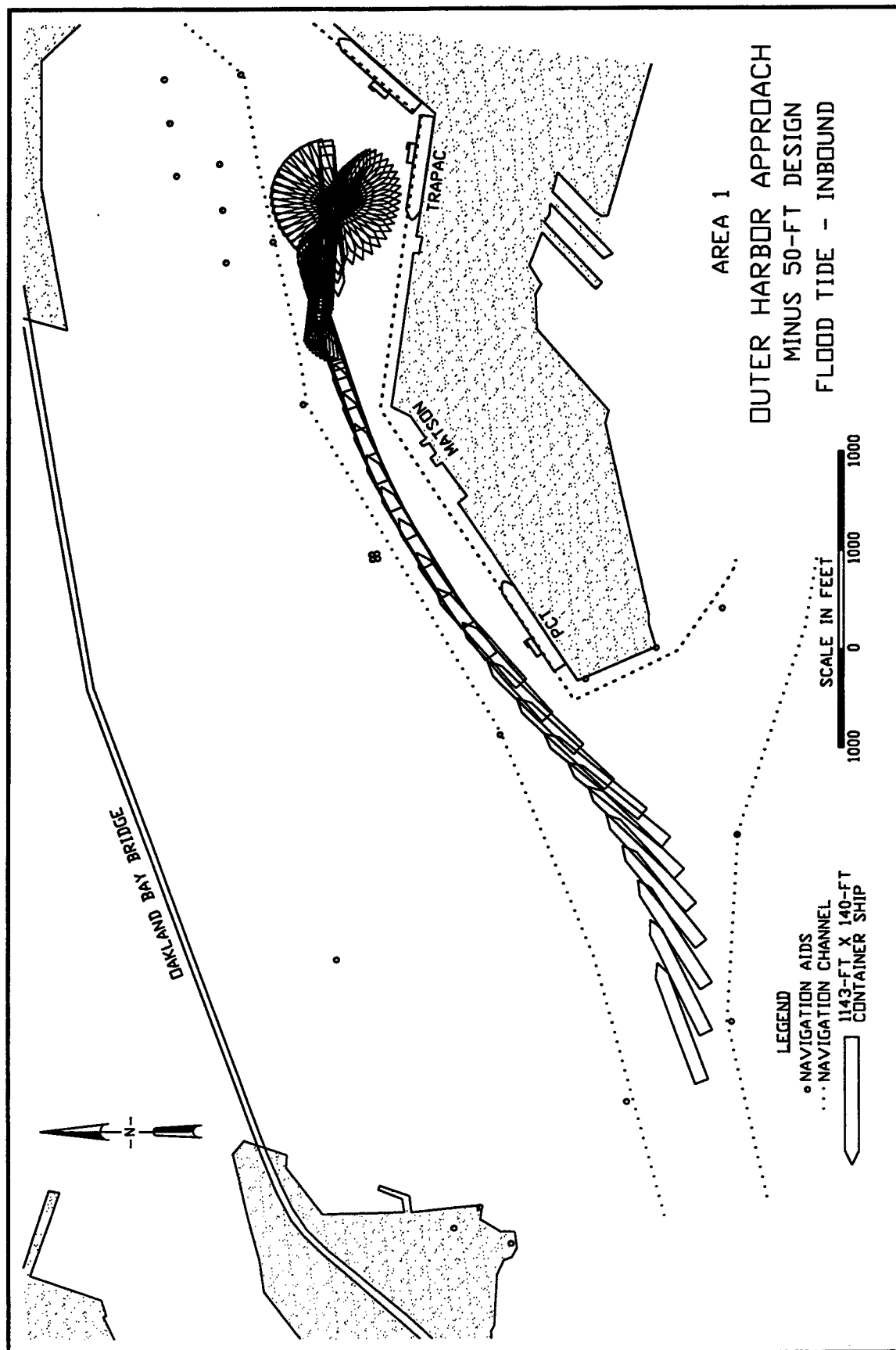


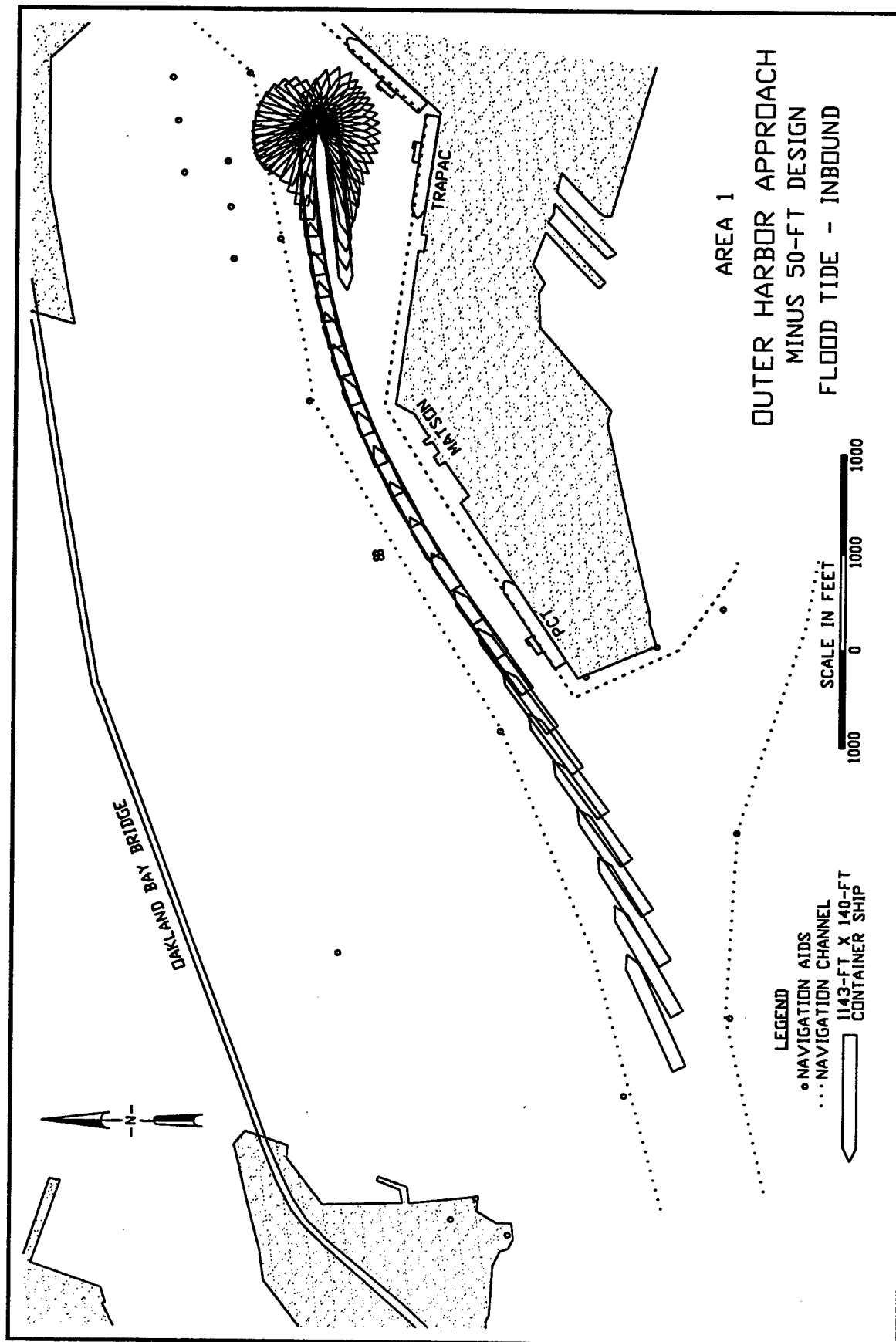


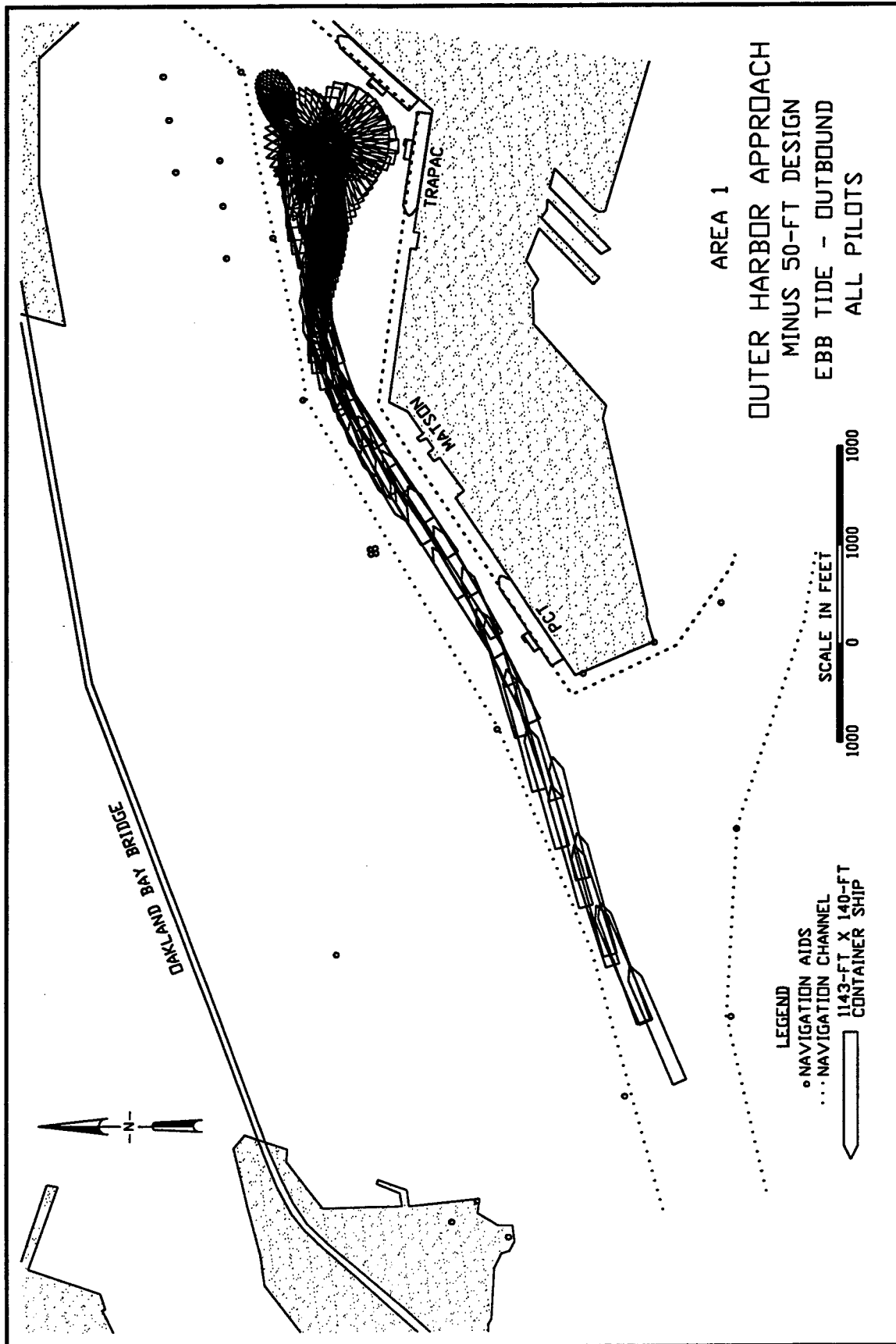


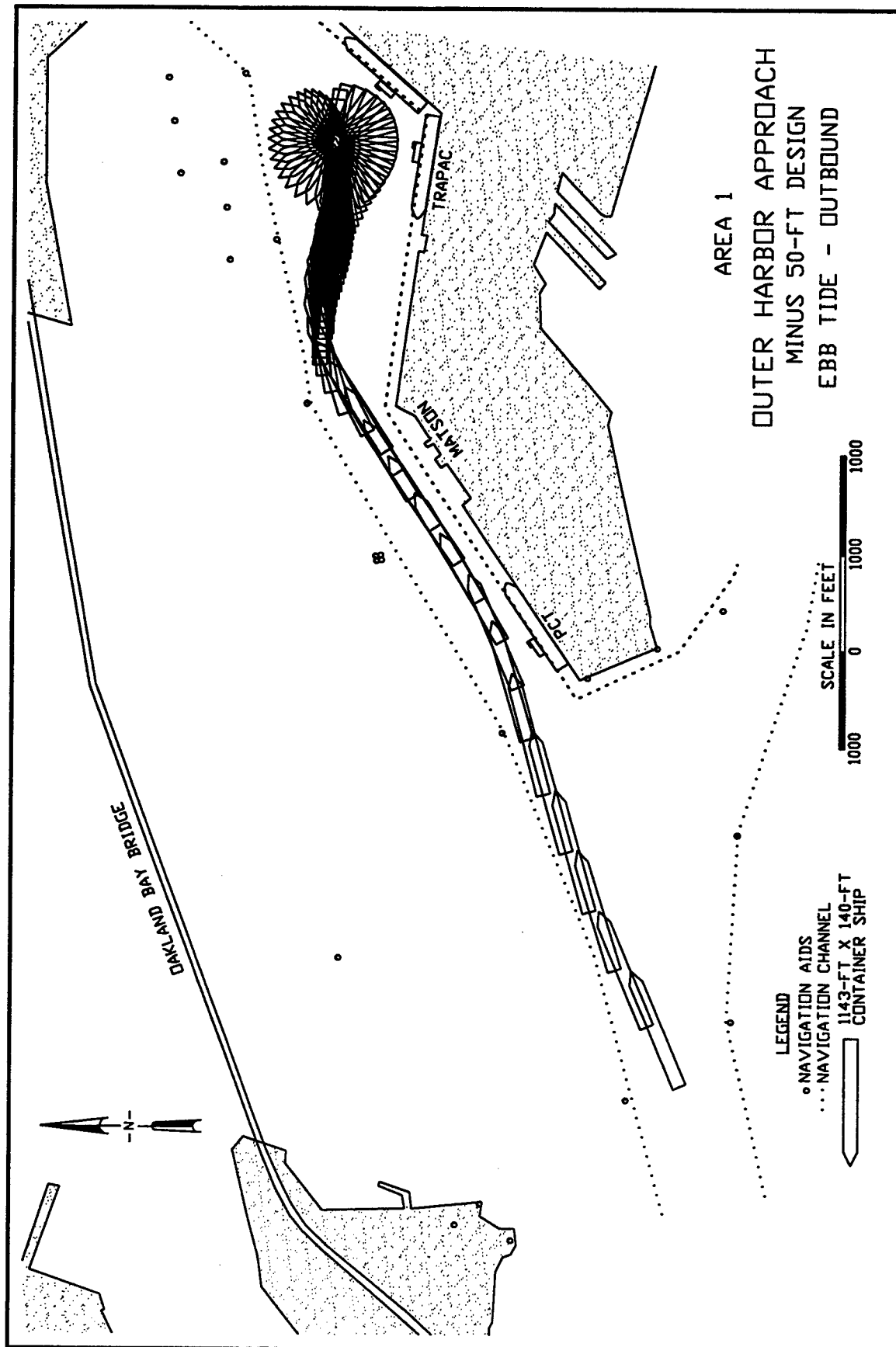


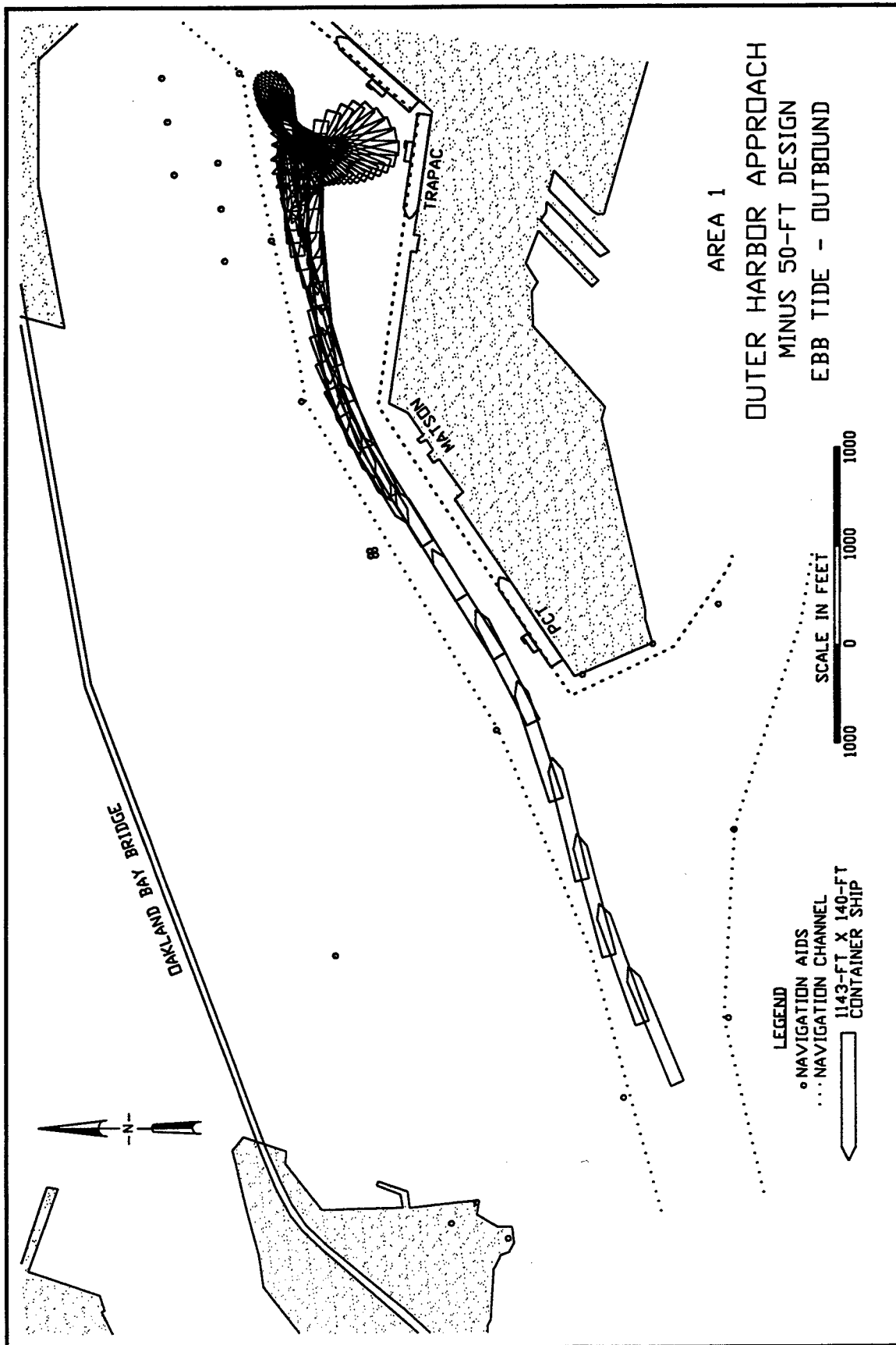


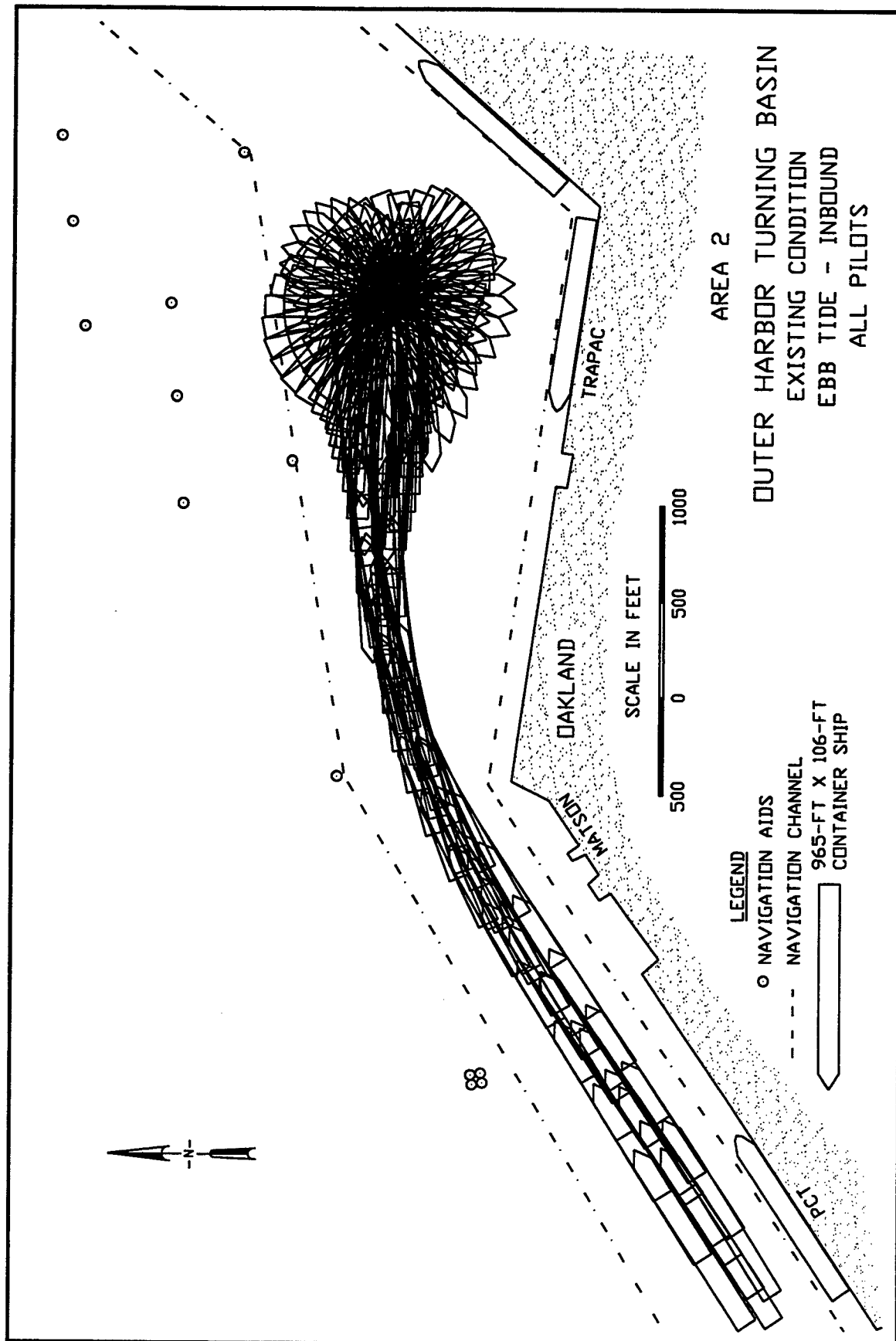


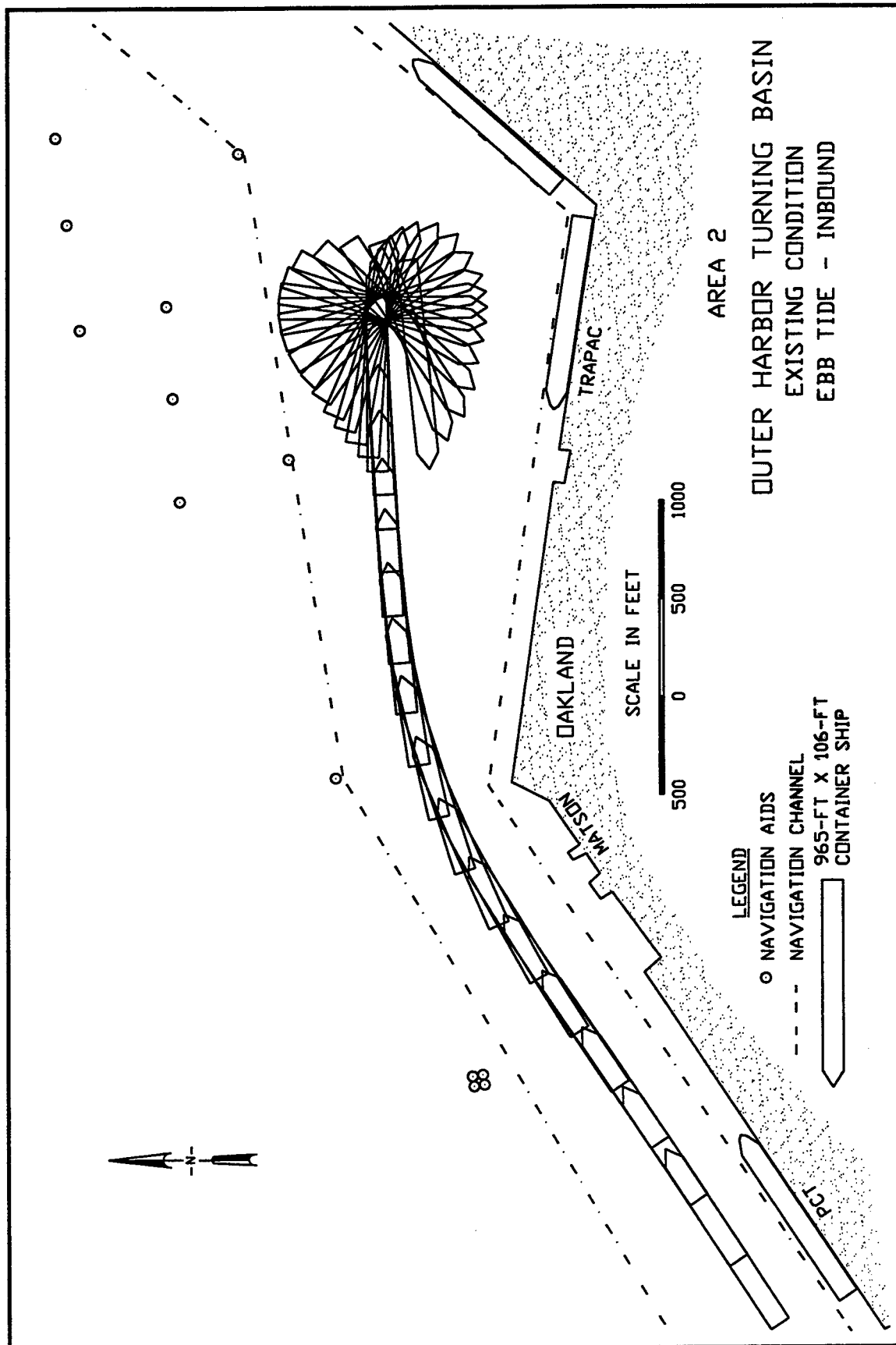


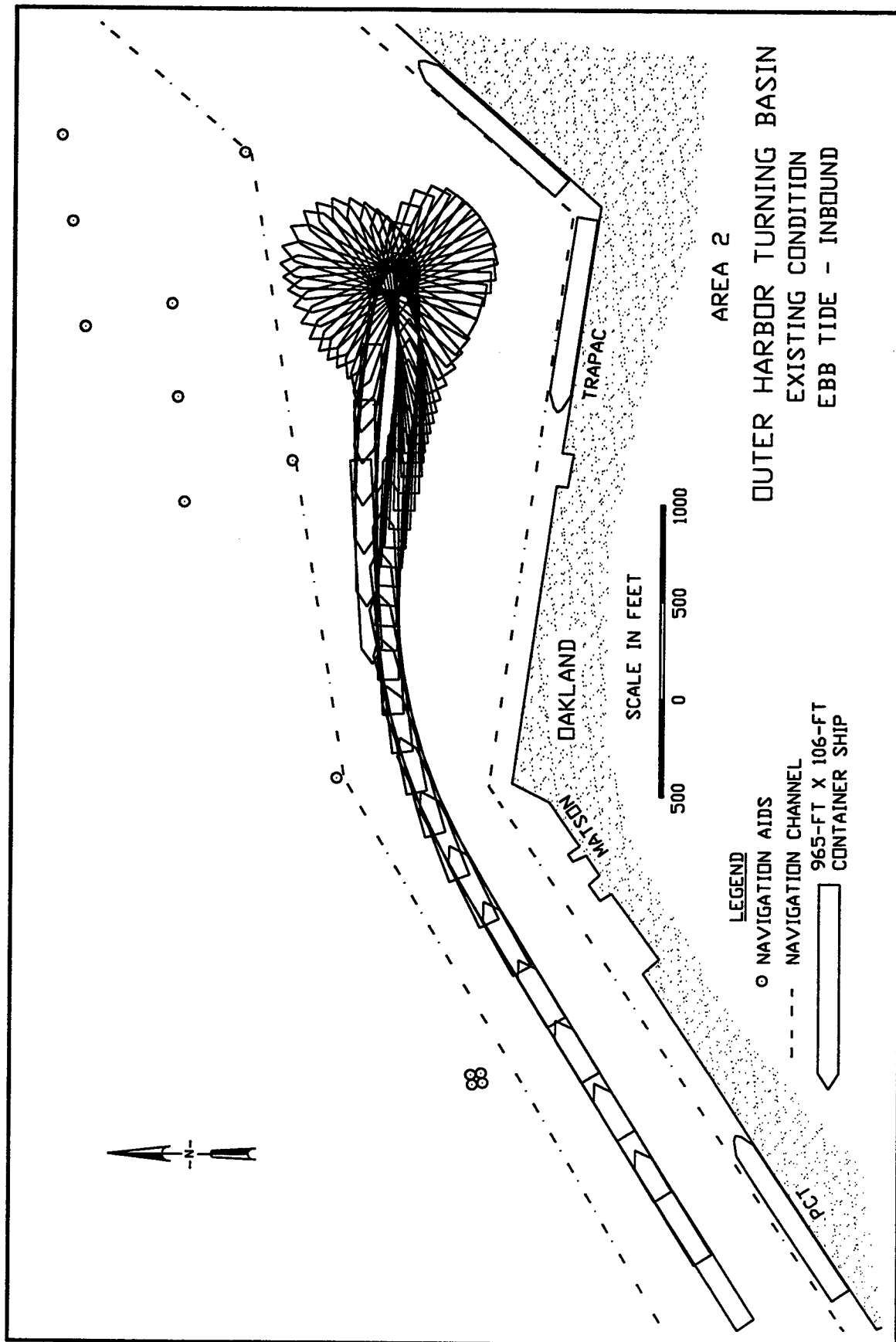


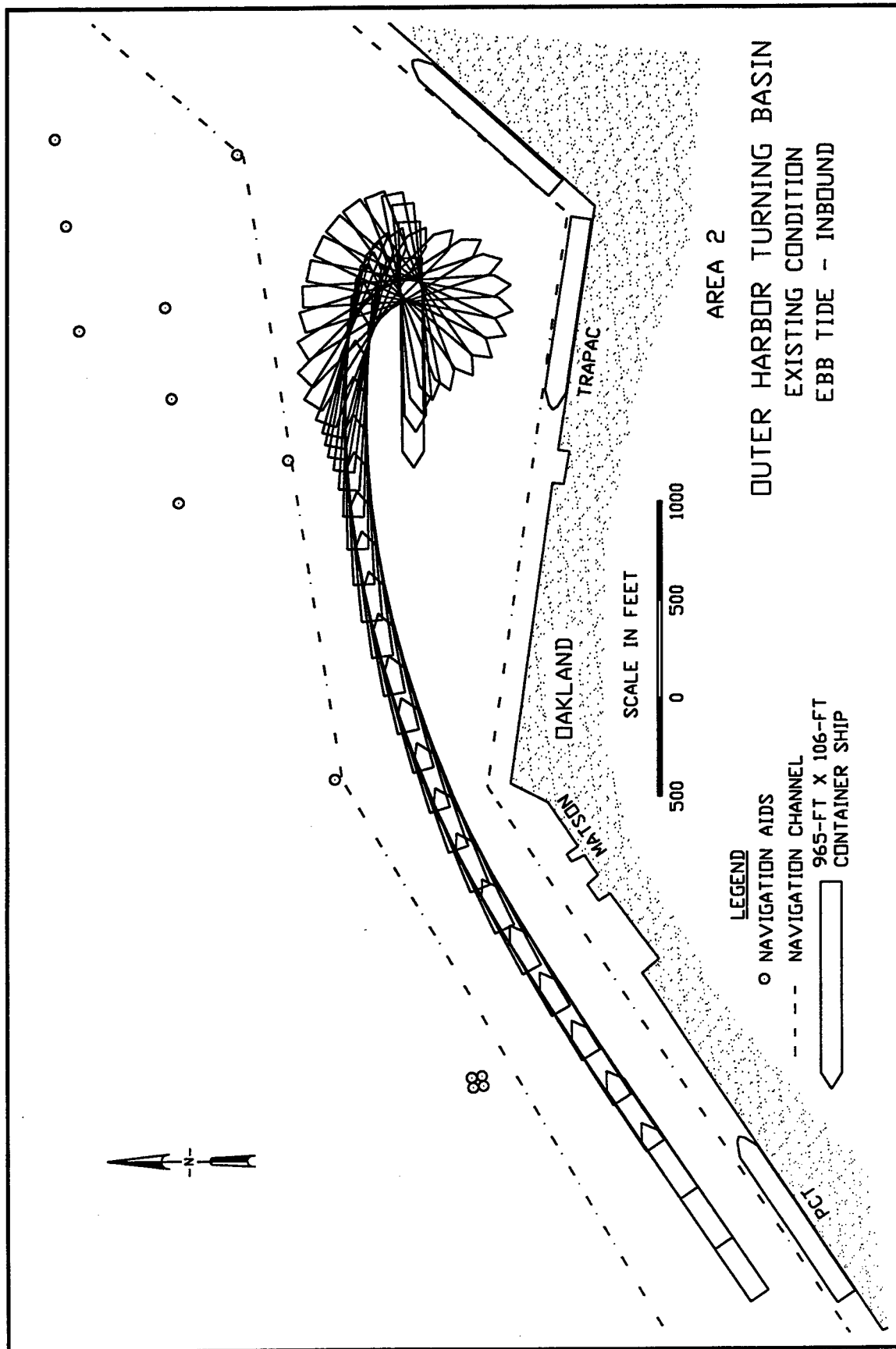


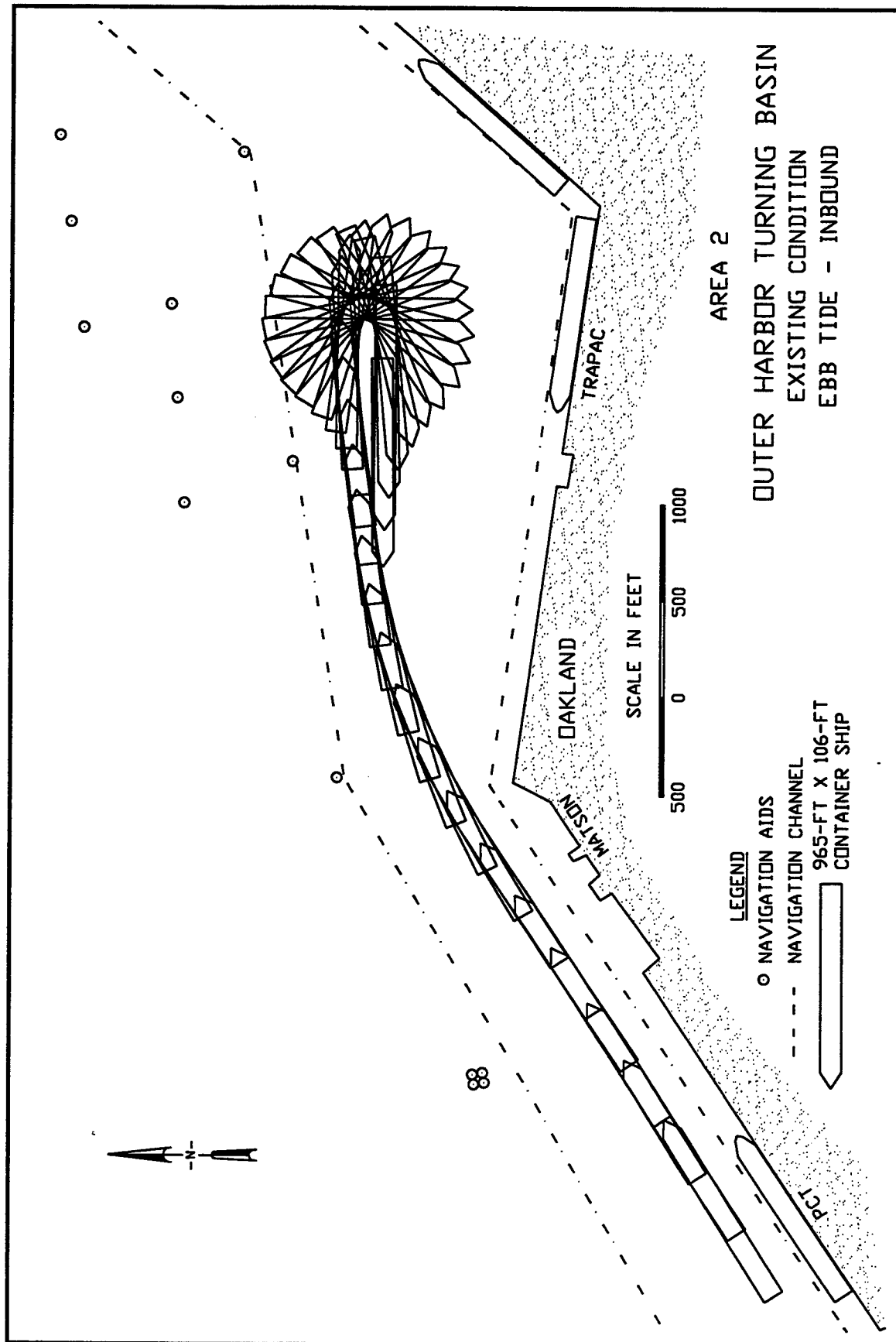


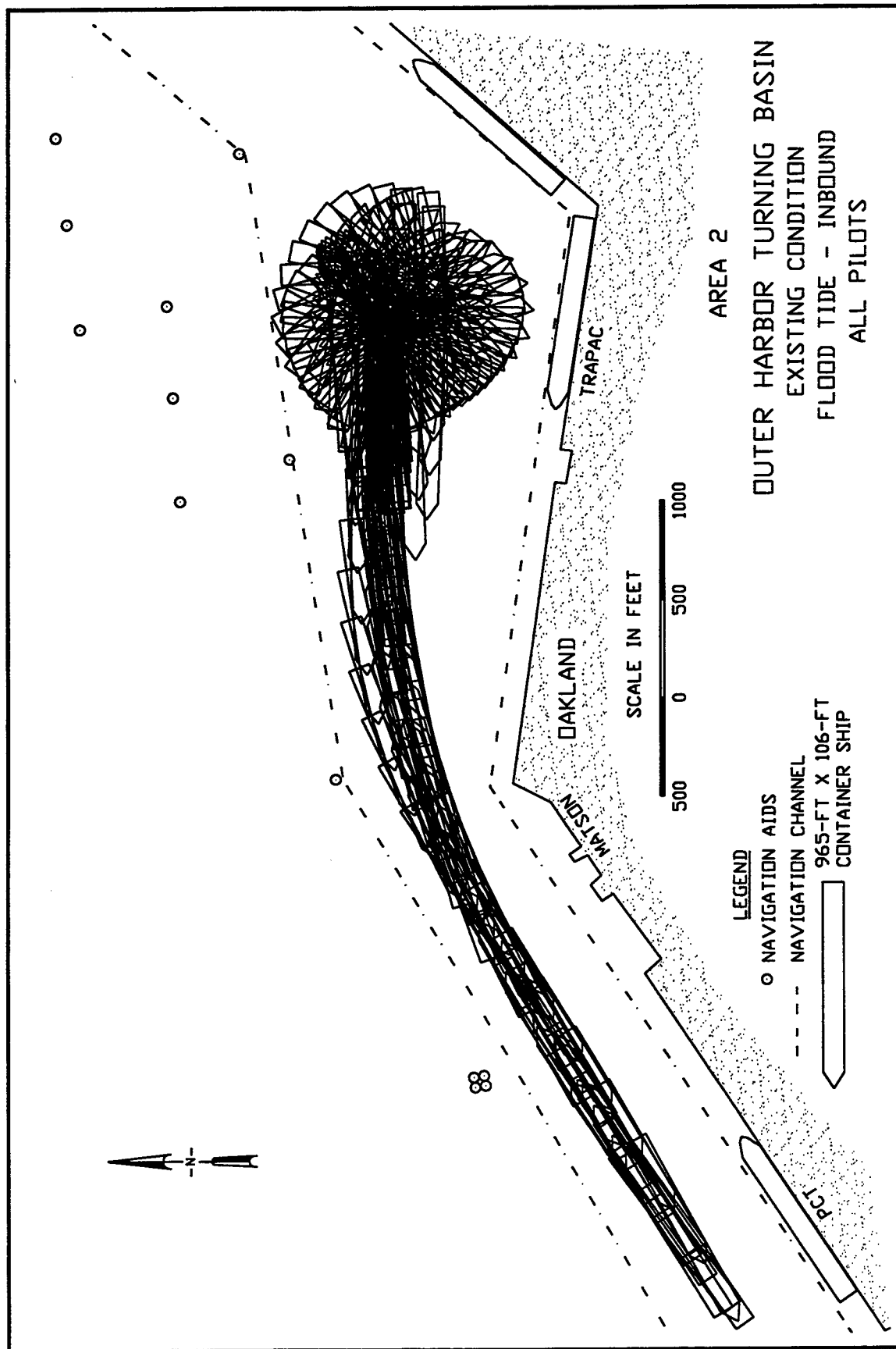




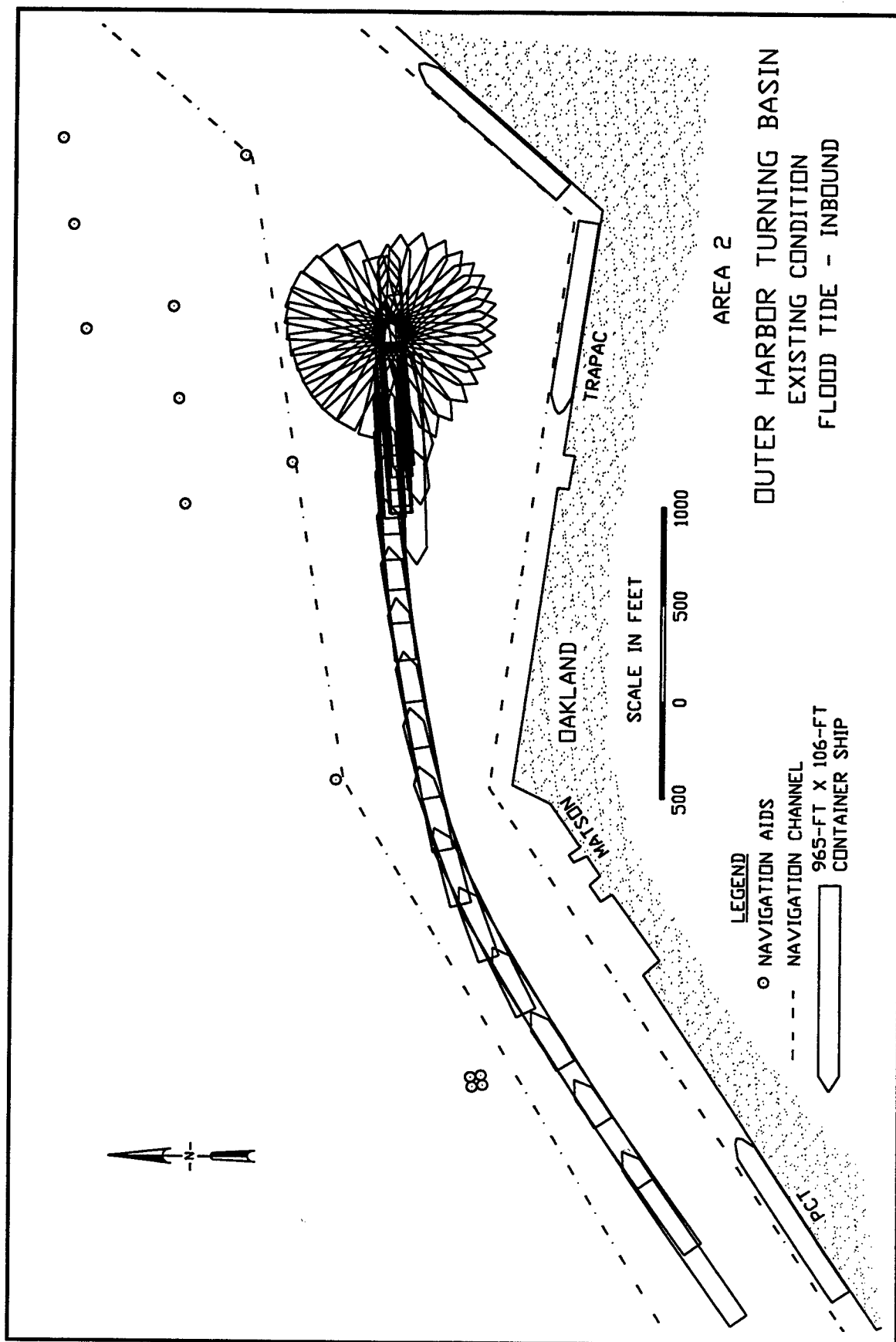


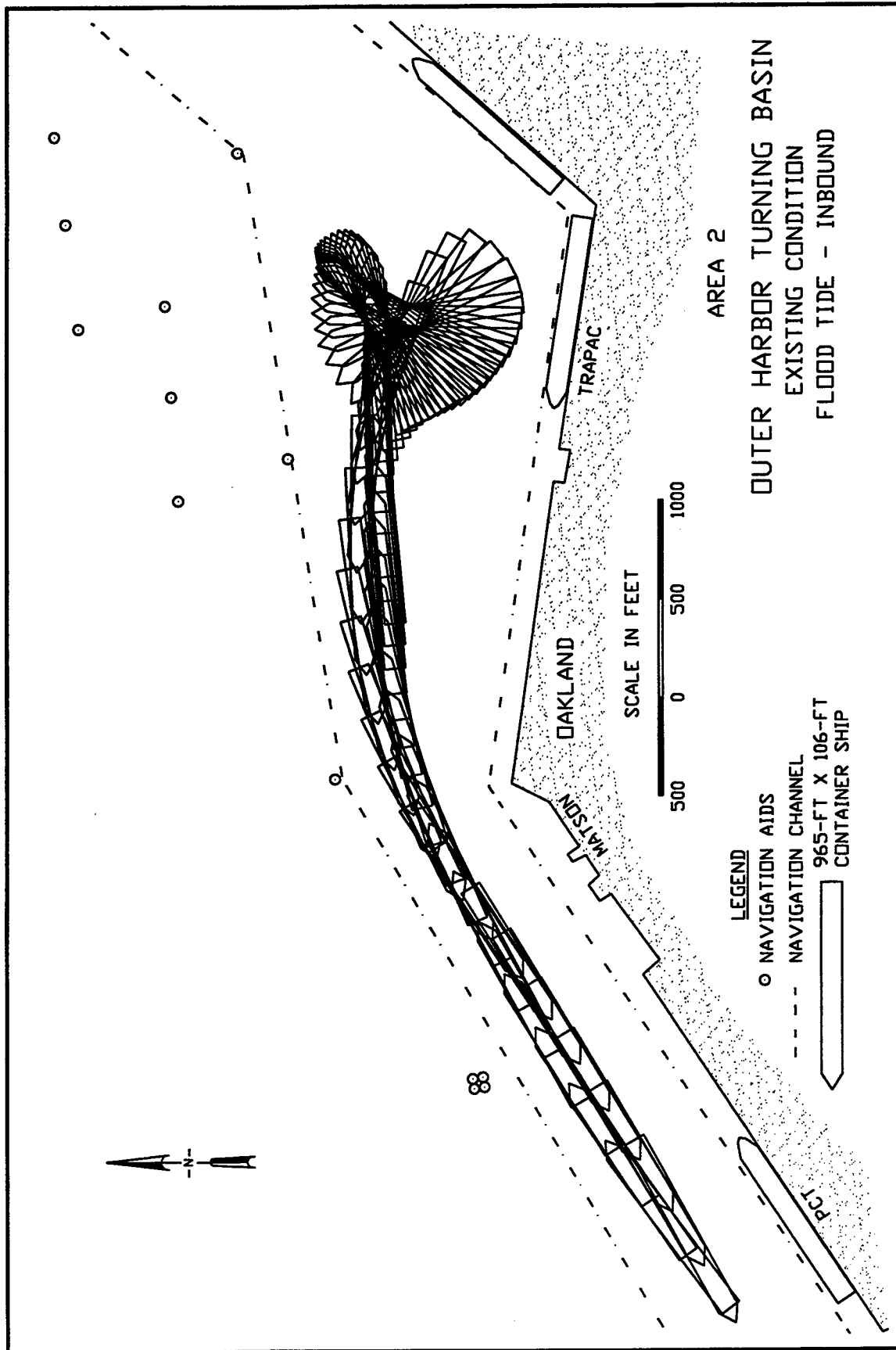


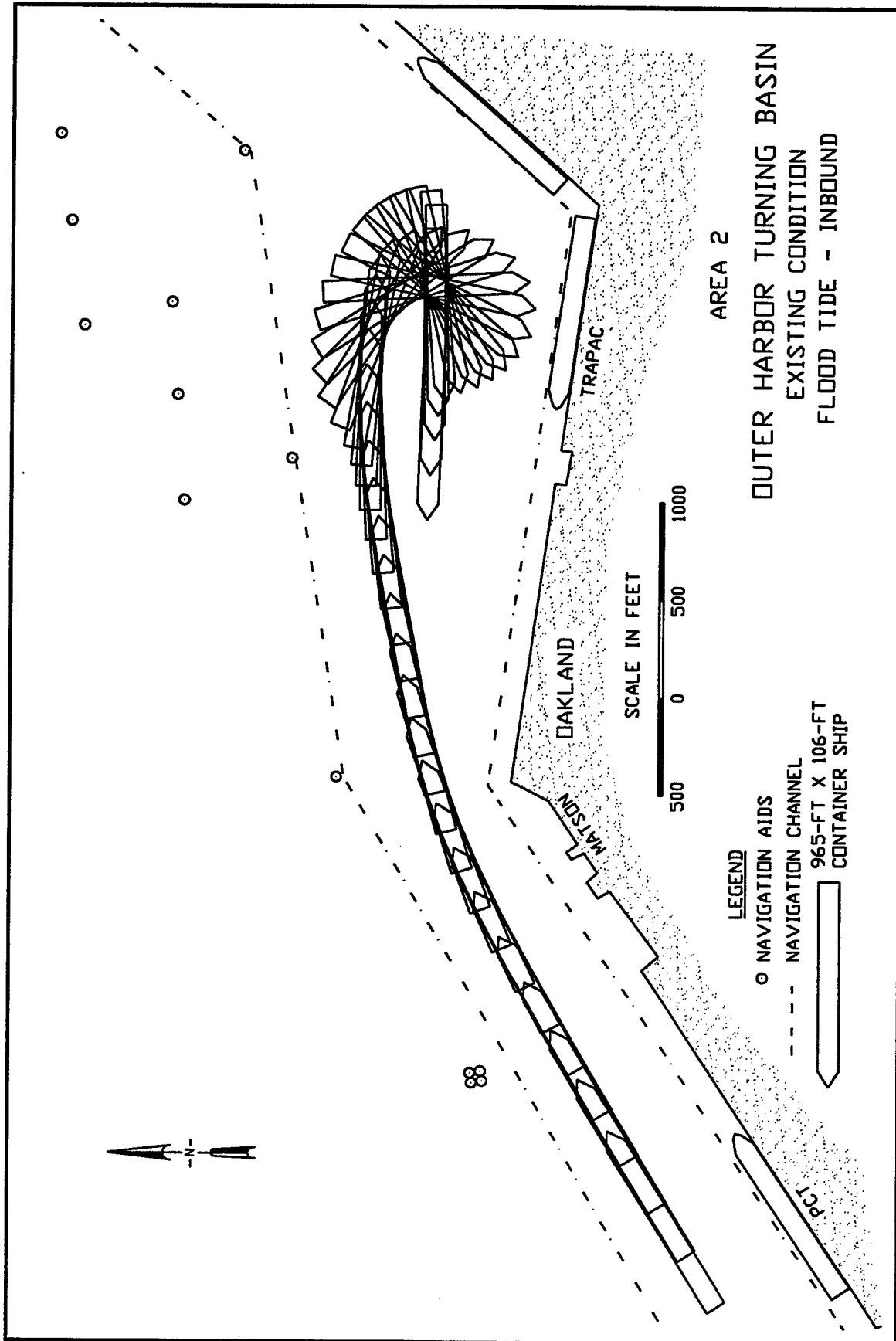


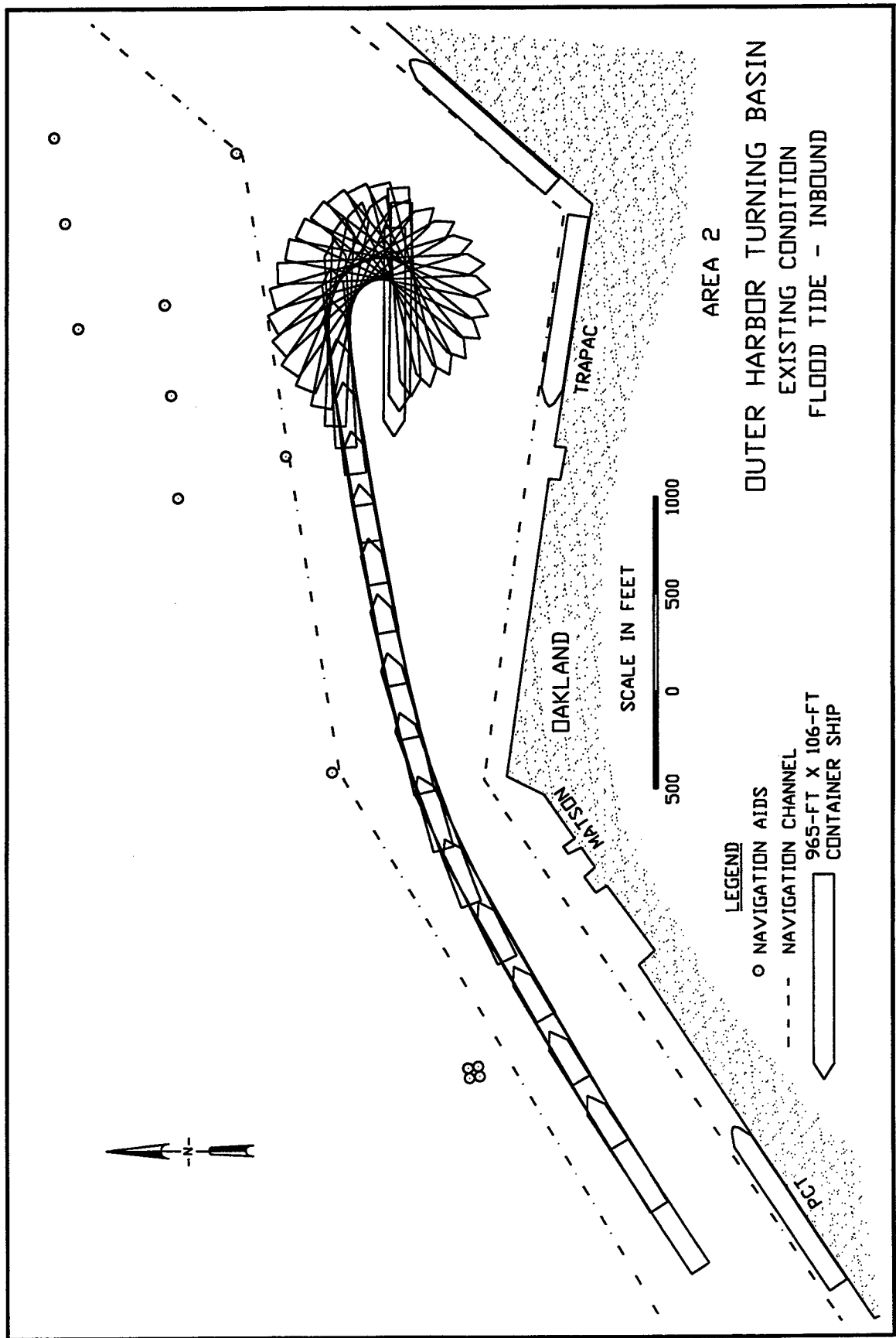


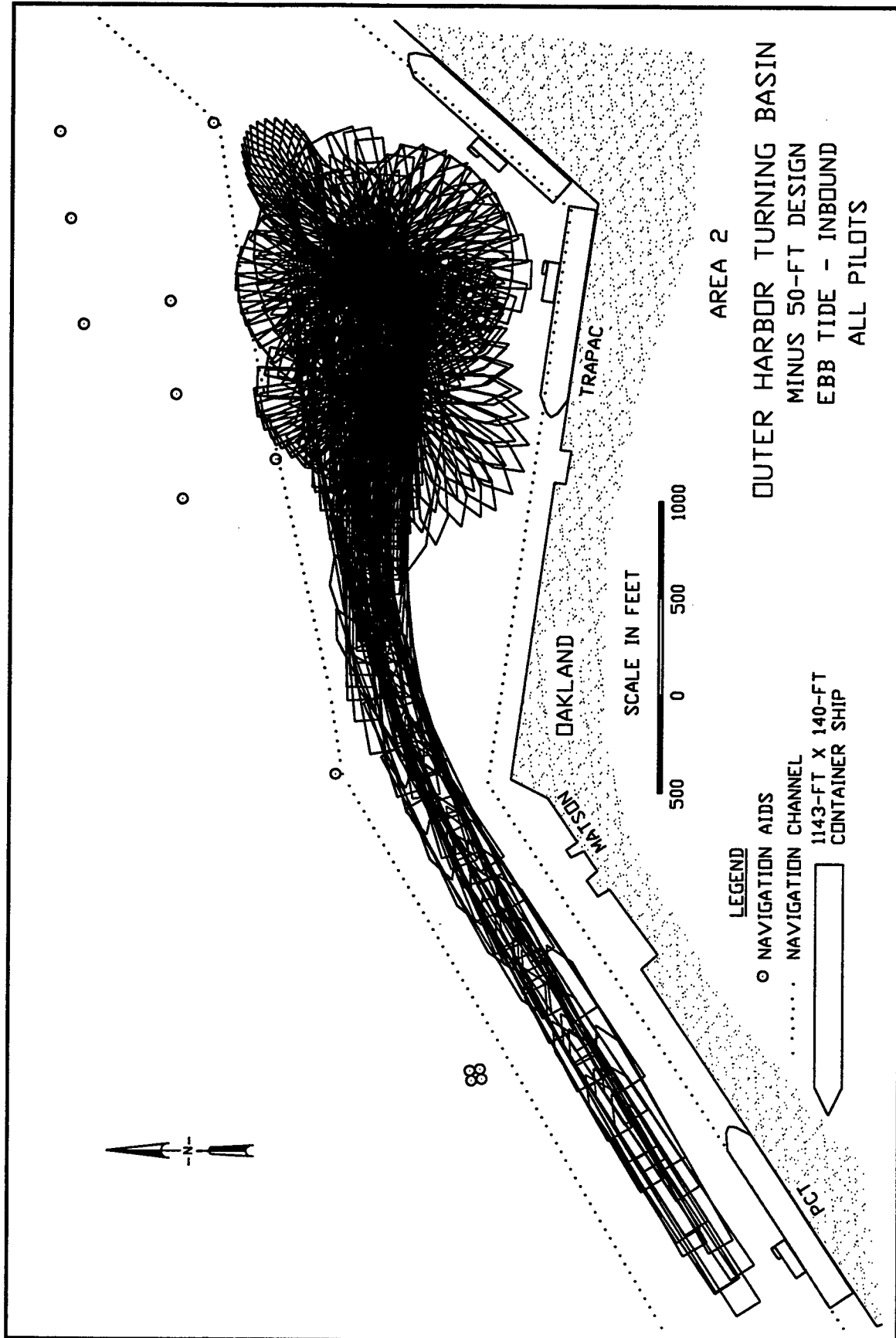
AREA 2
 OUTER HARBOR TURNING BASIN
 EXISTING CONDITION
 FLOOD TIDE - INBOUND
 ALL PILOTS

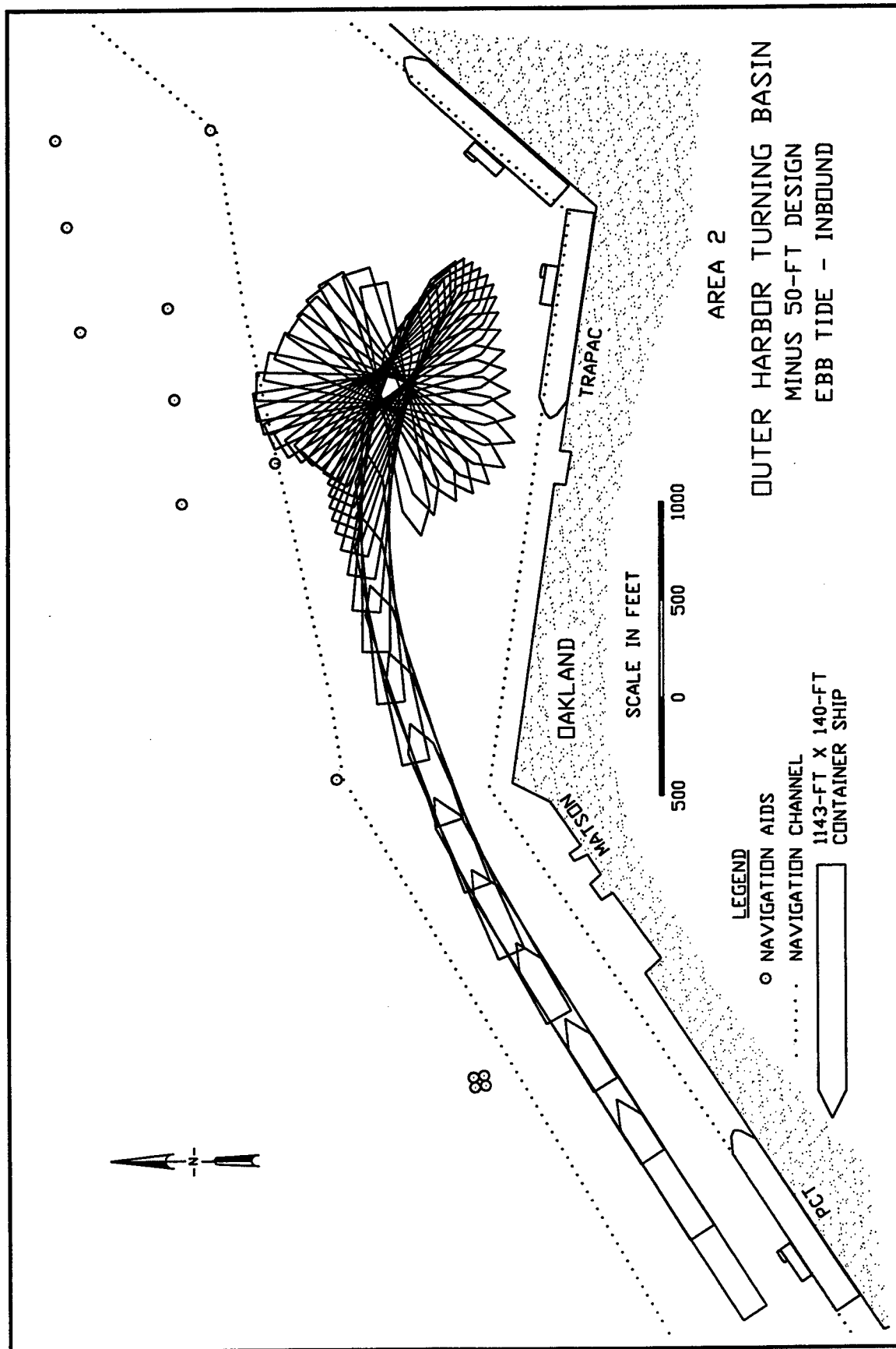


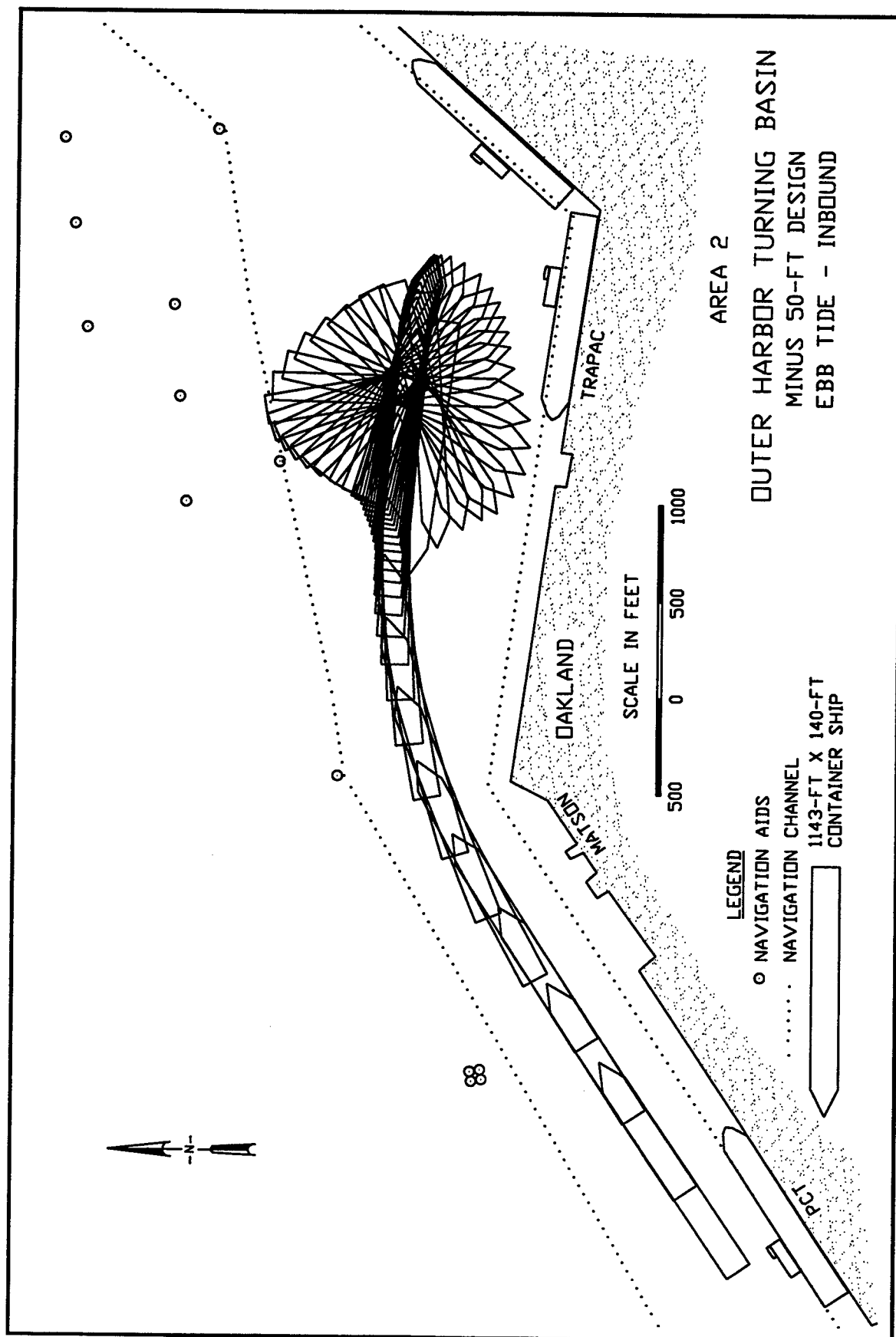


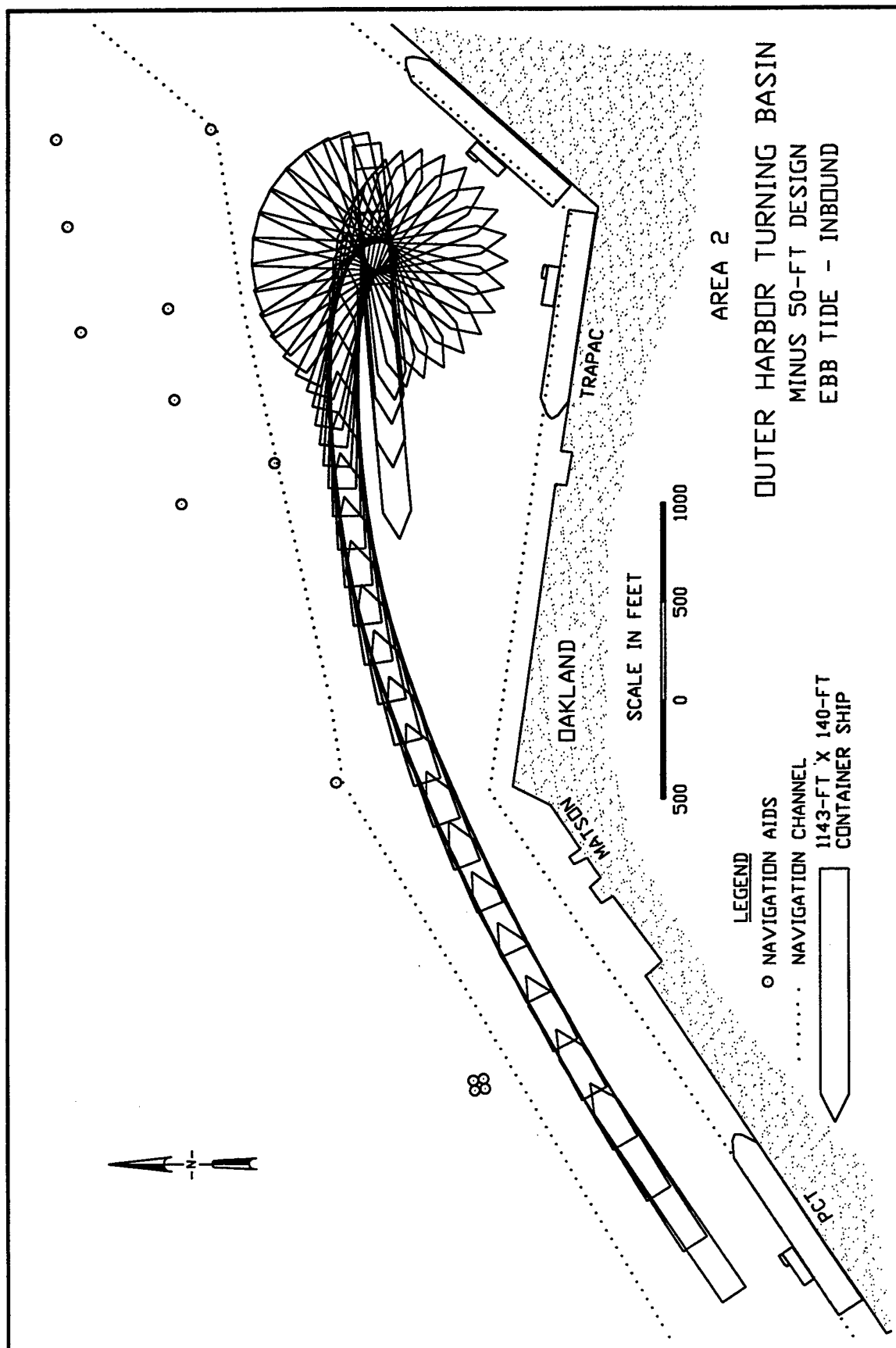


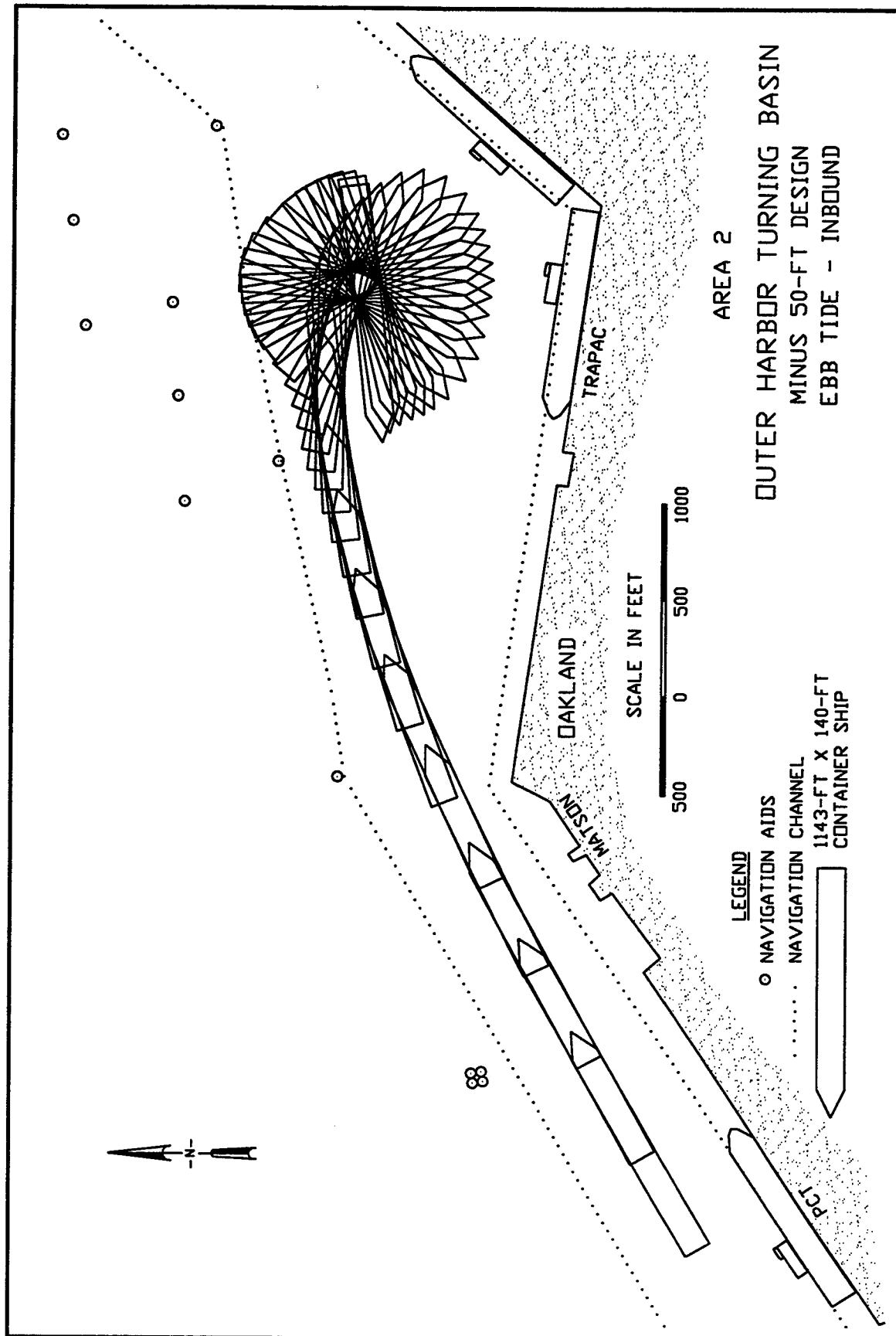


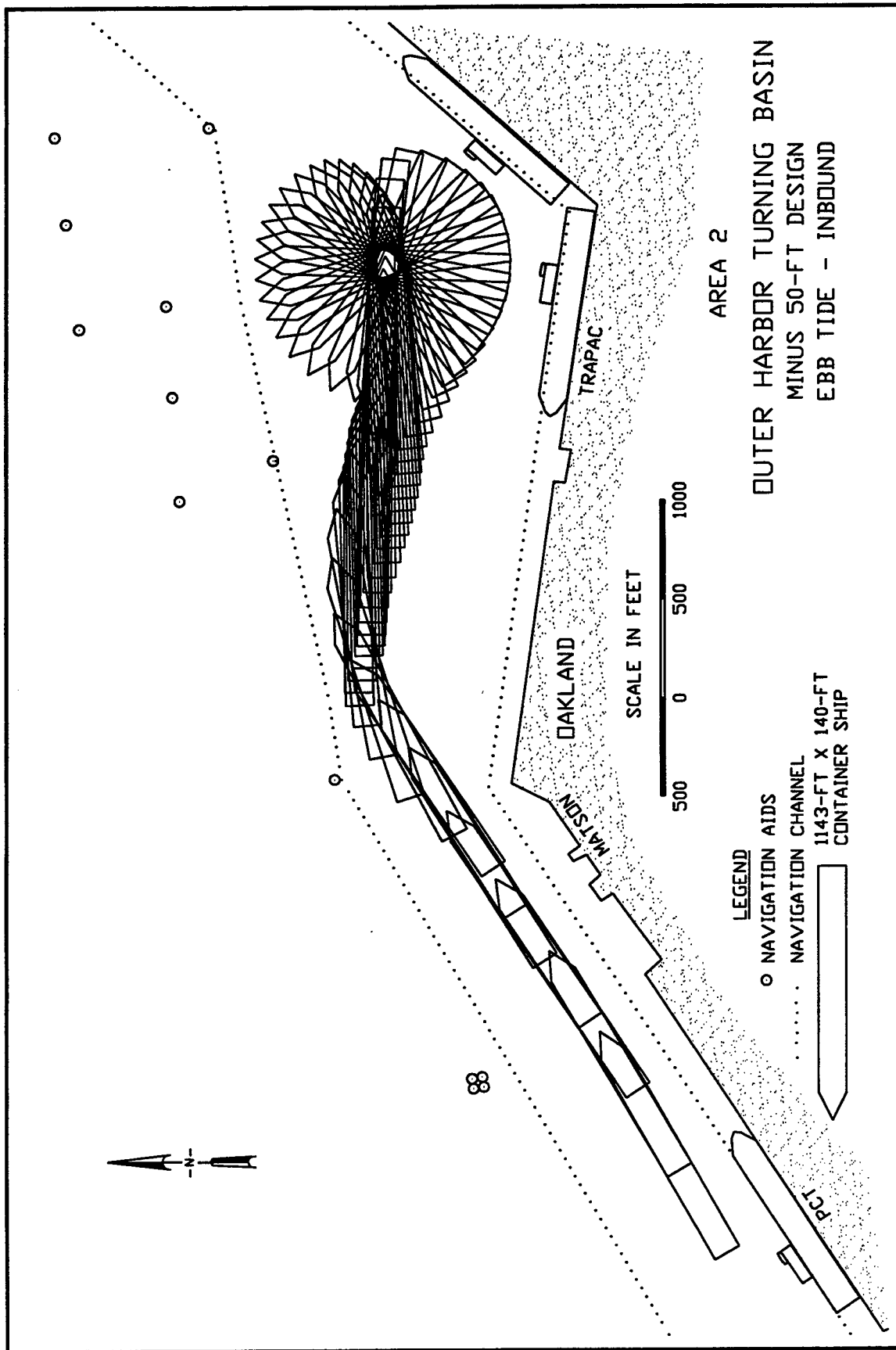


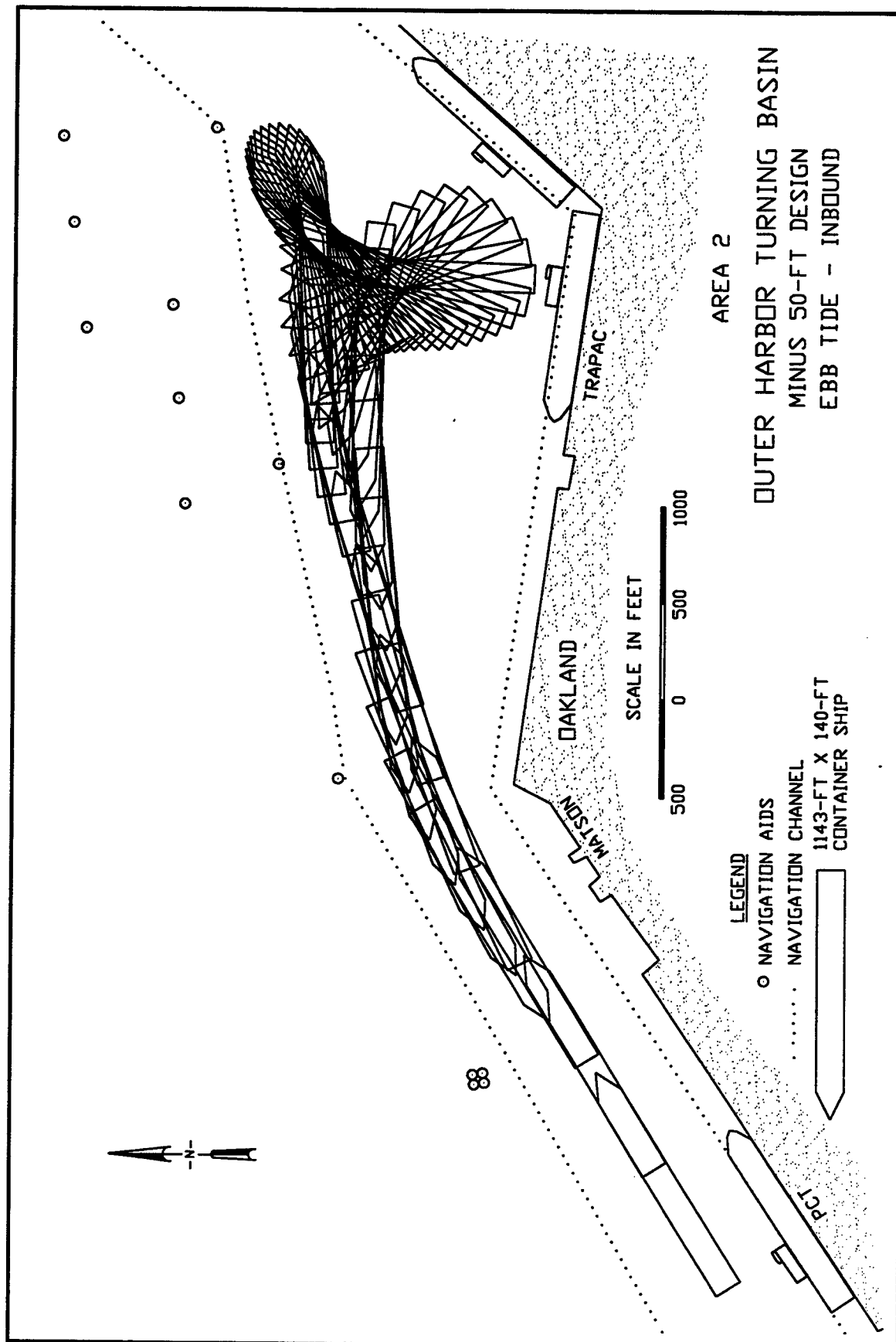


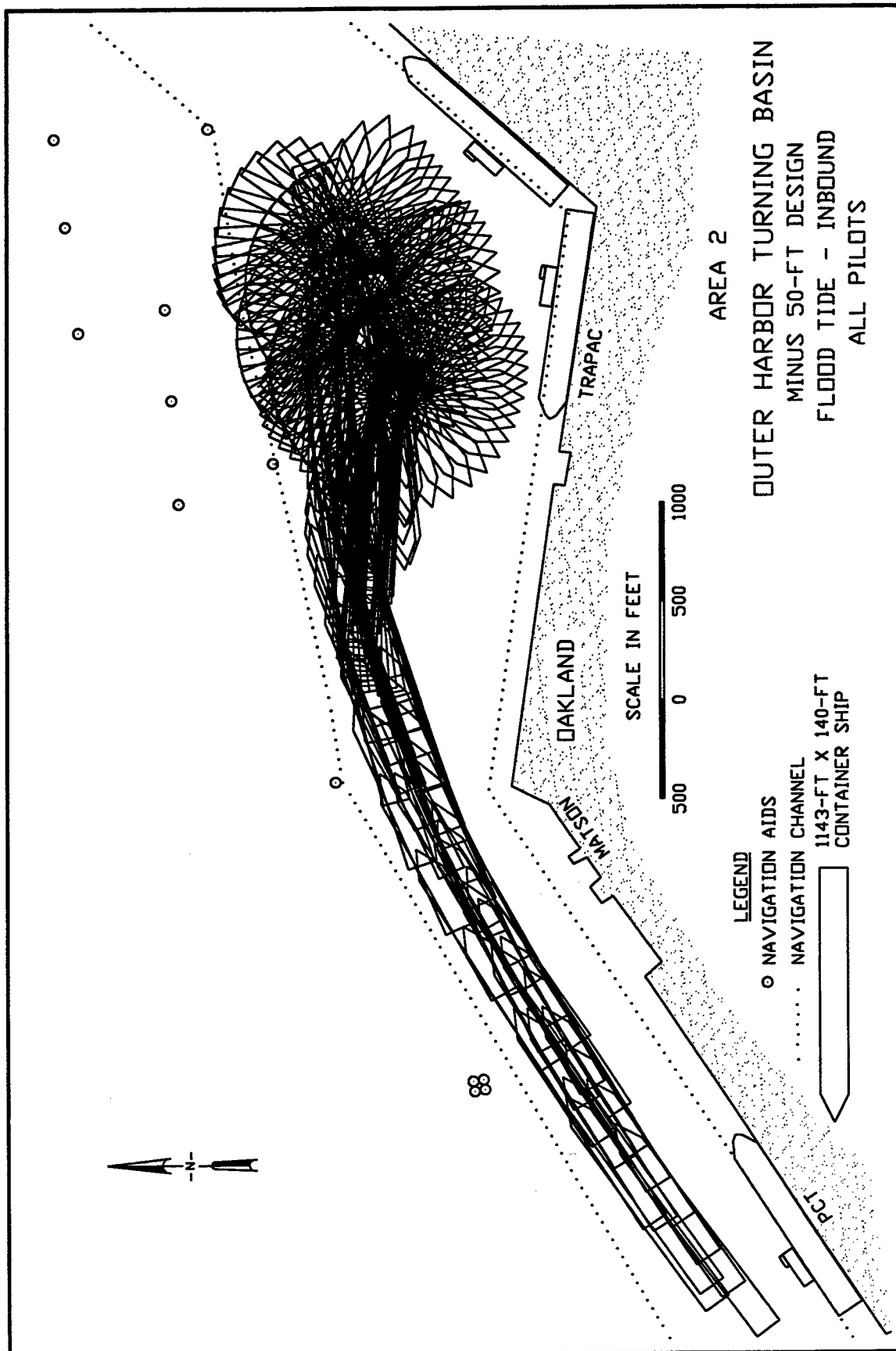


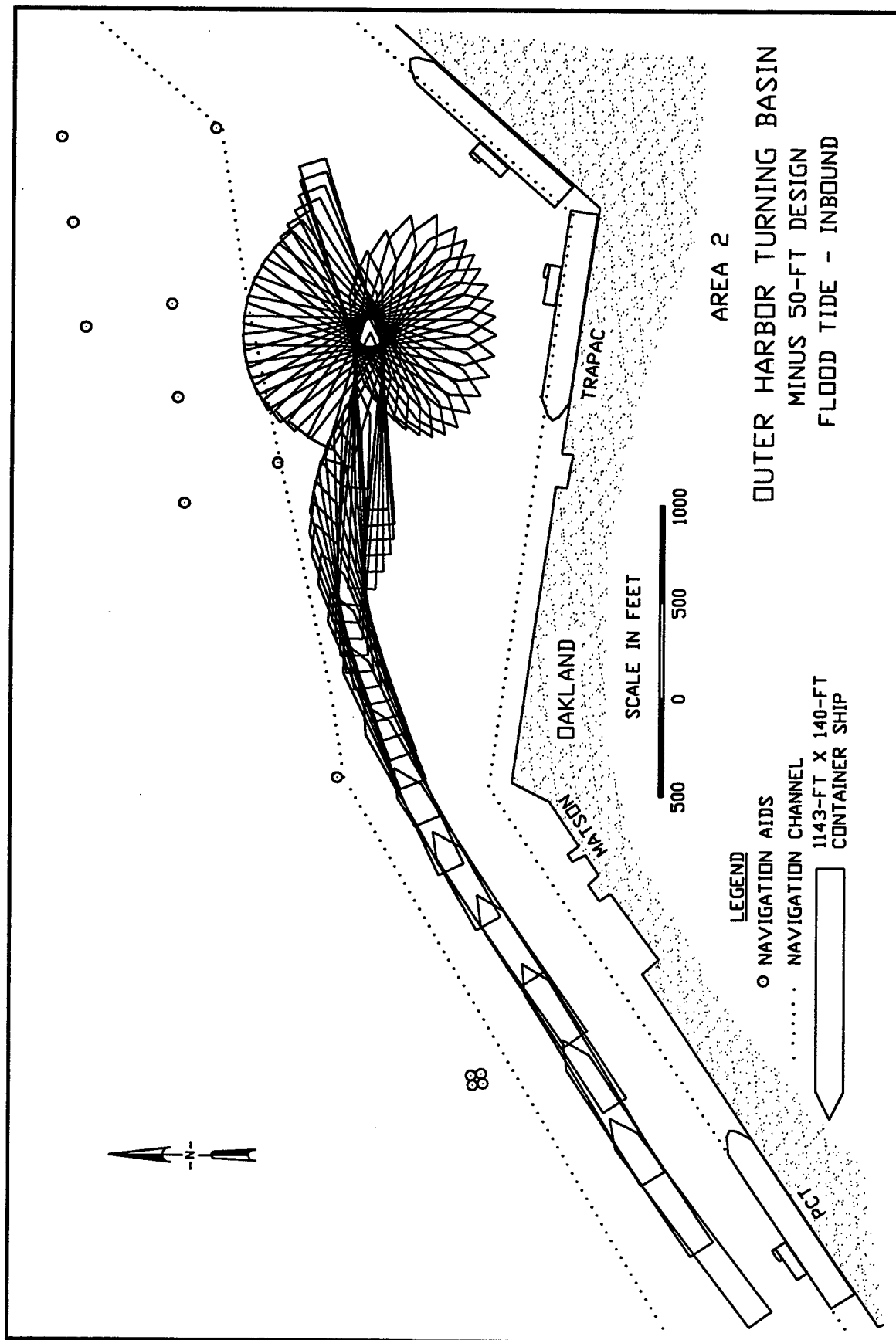


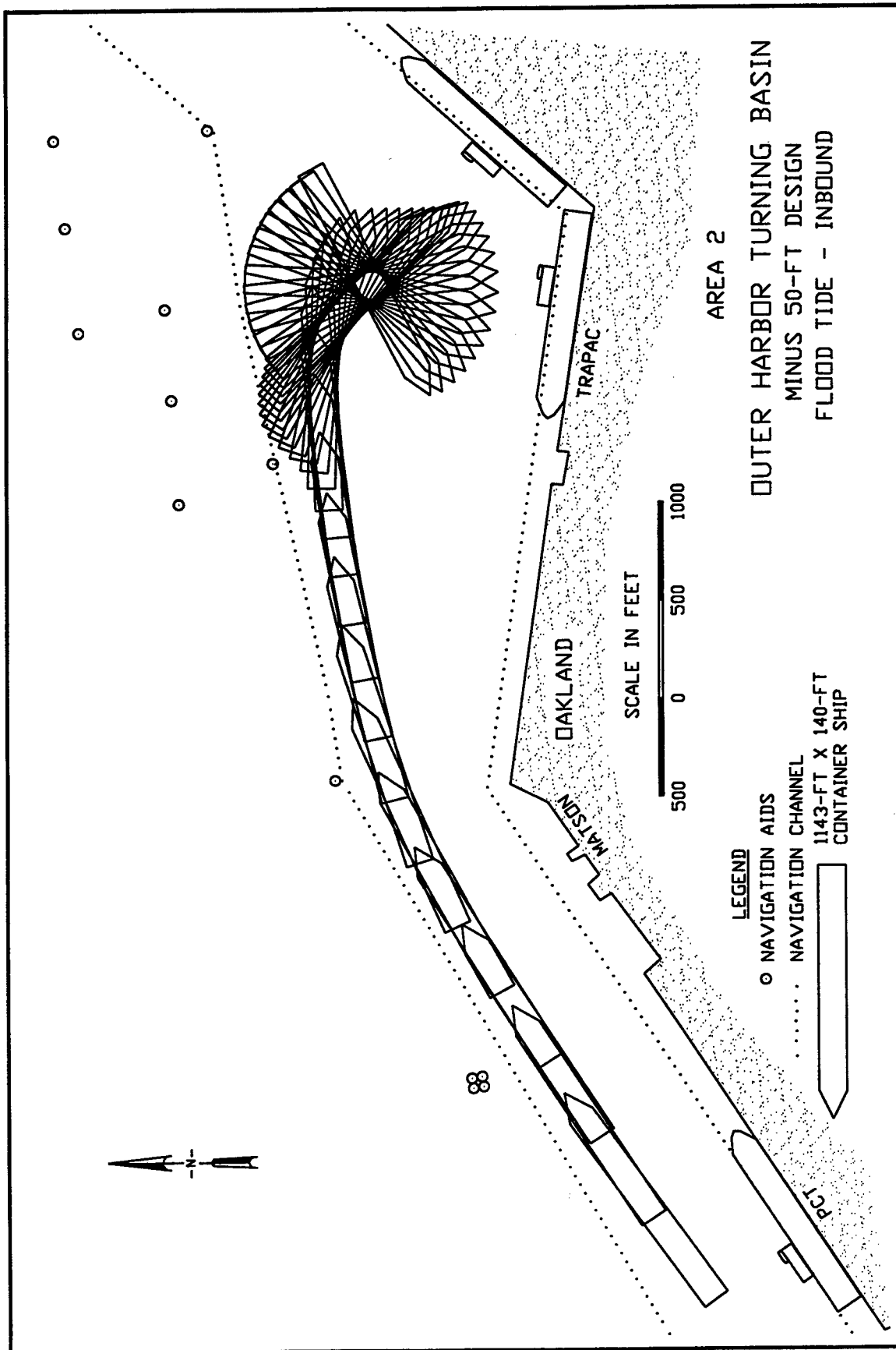


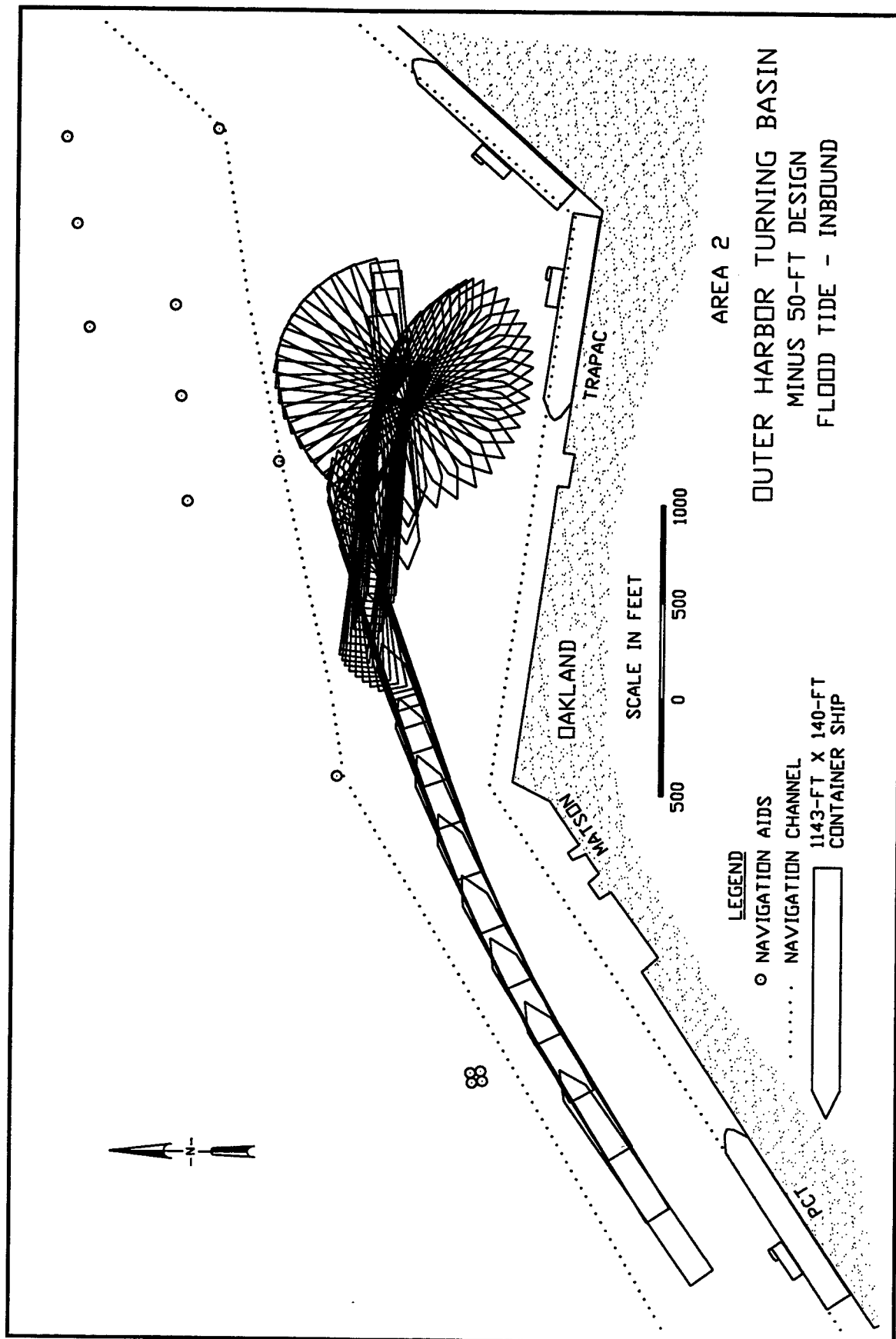


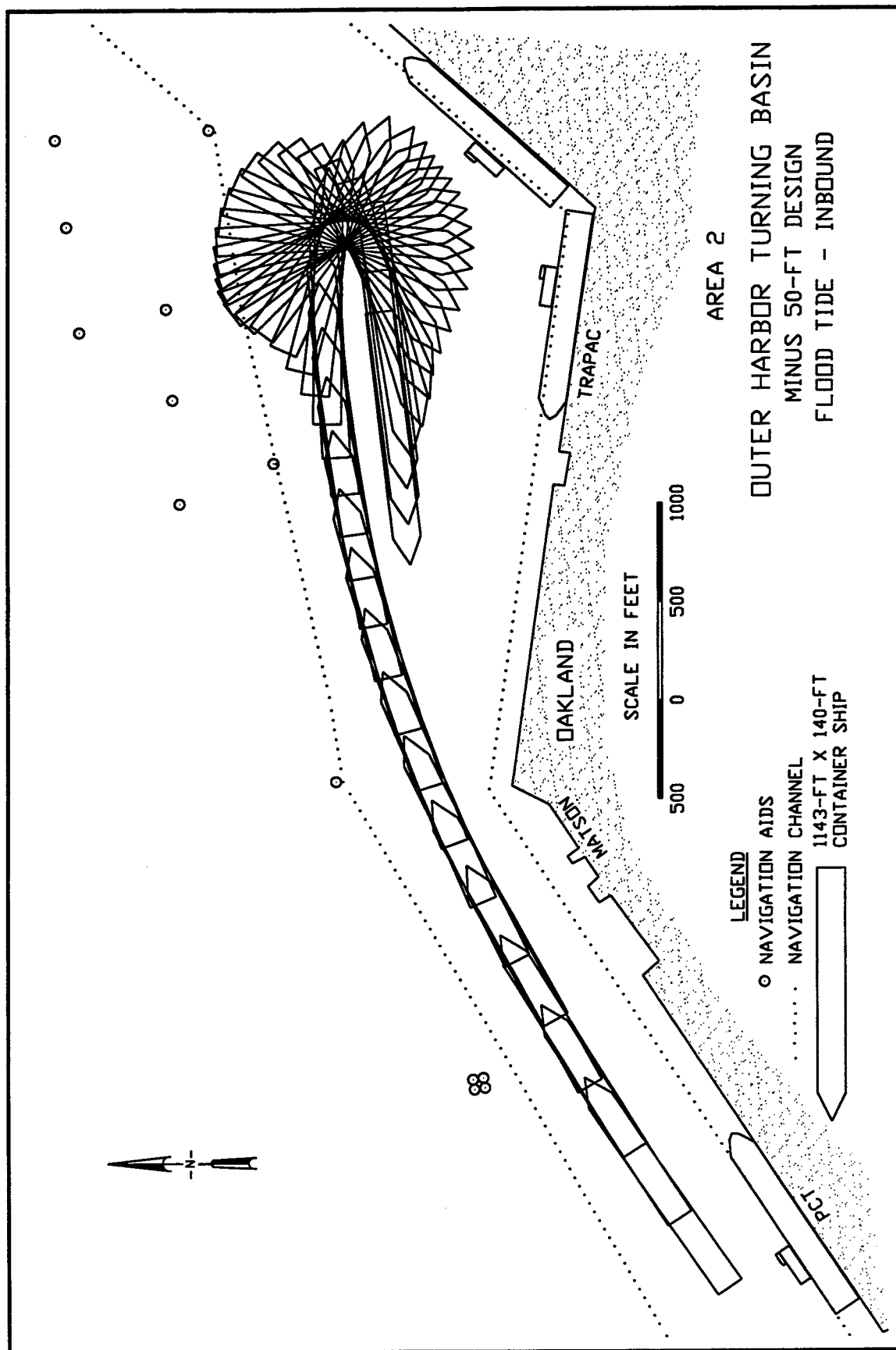


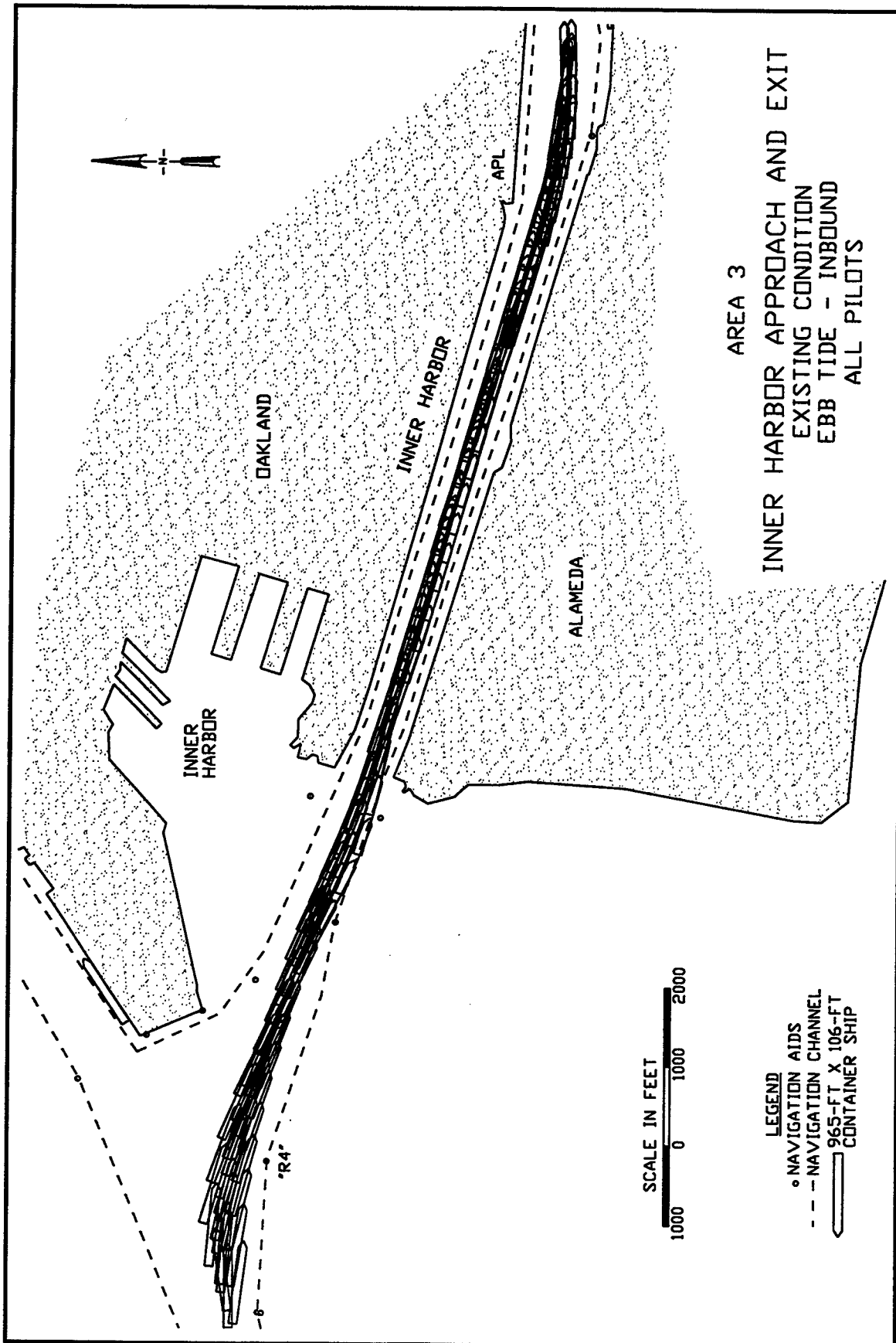


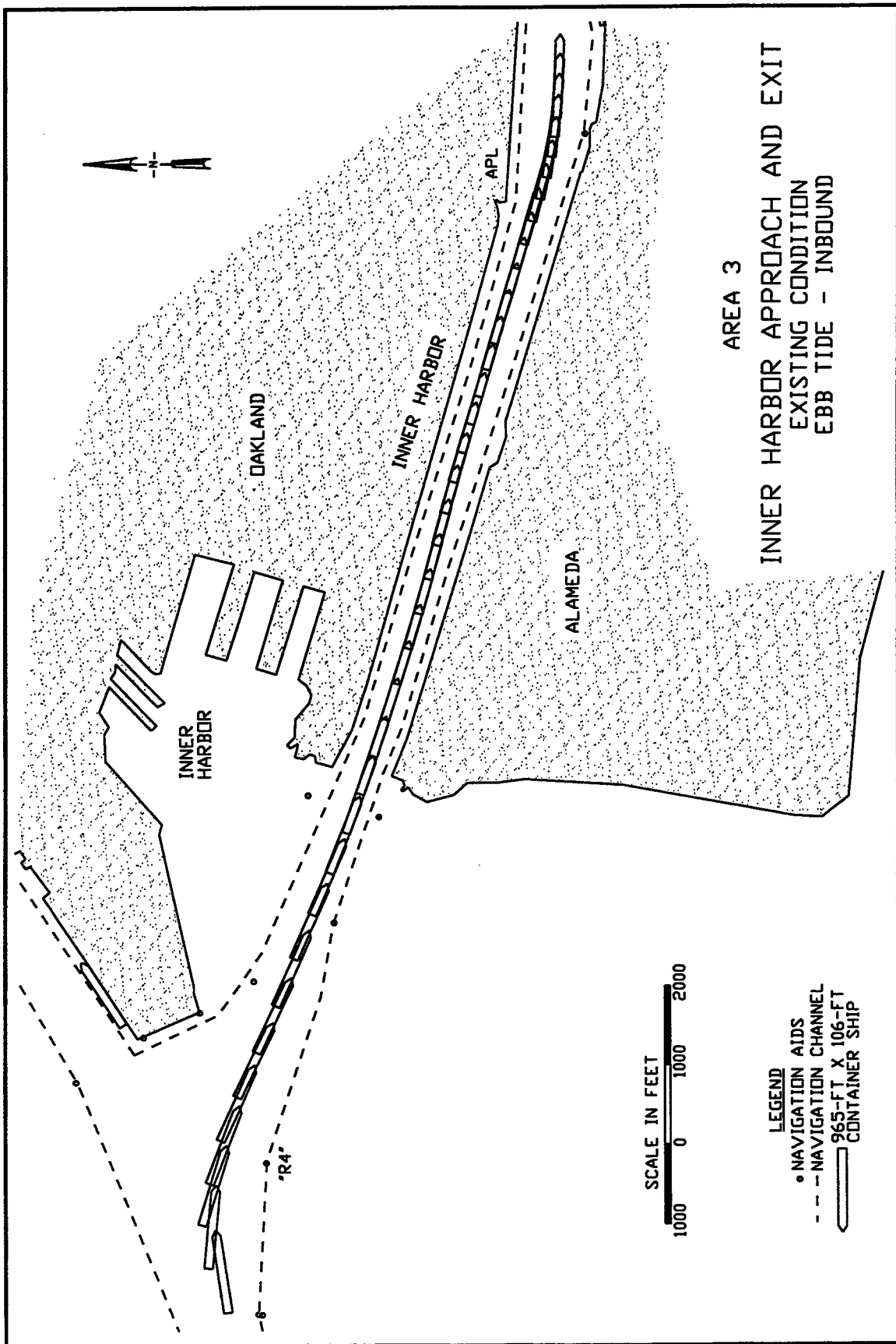


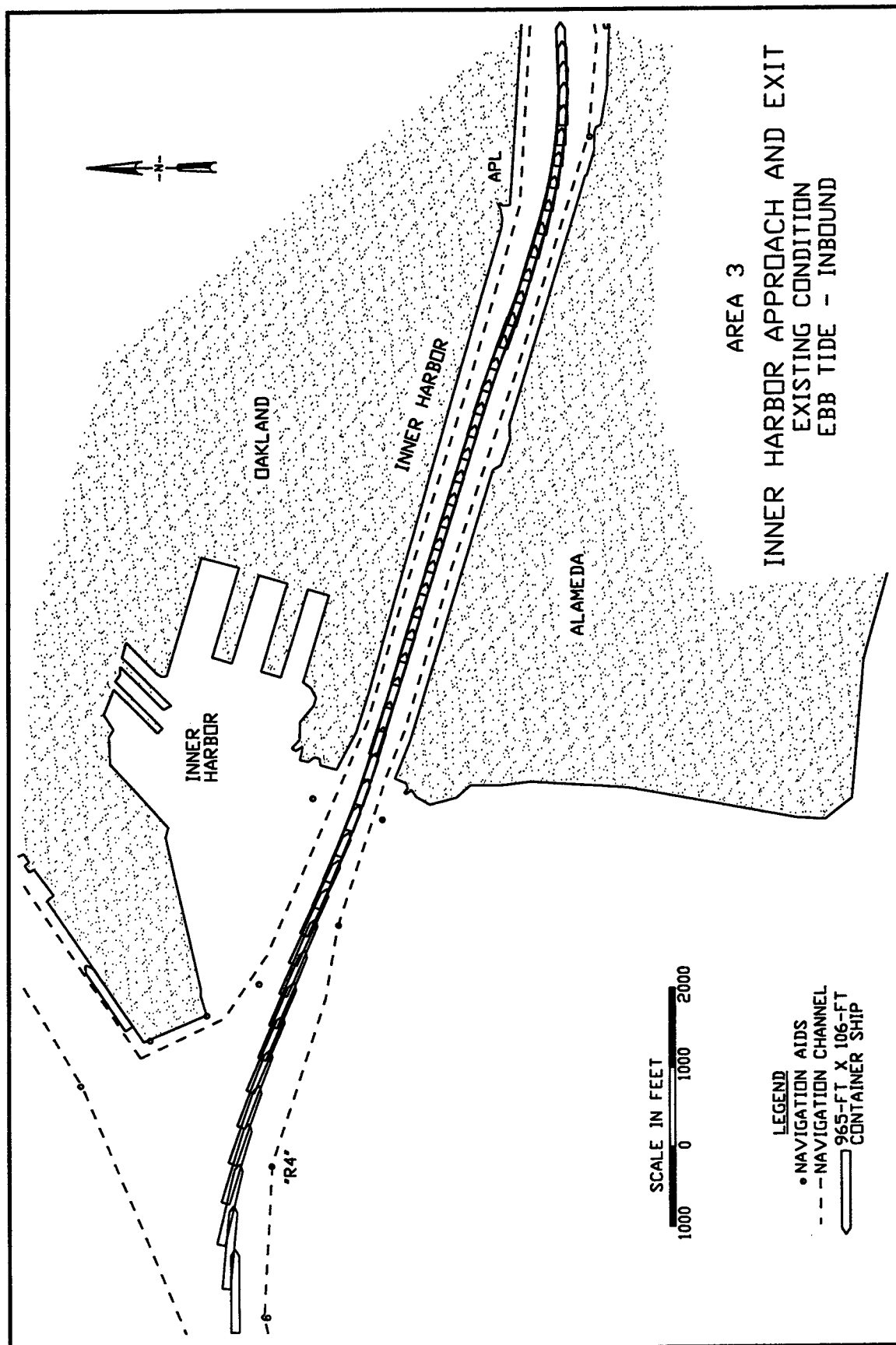


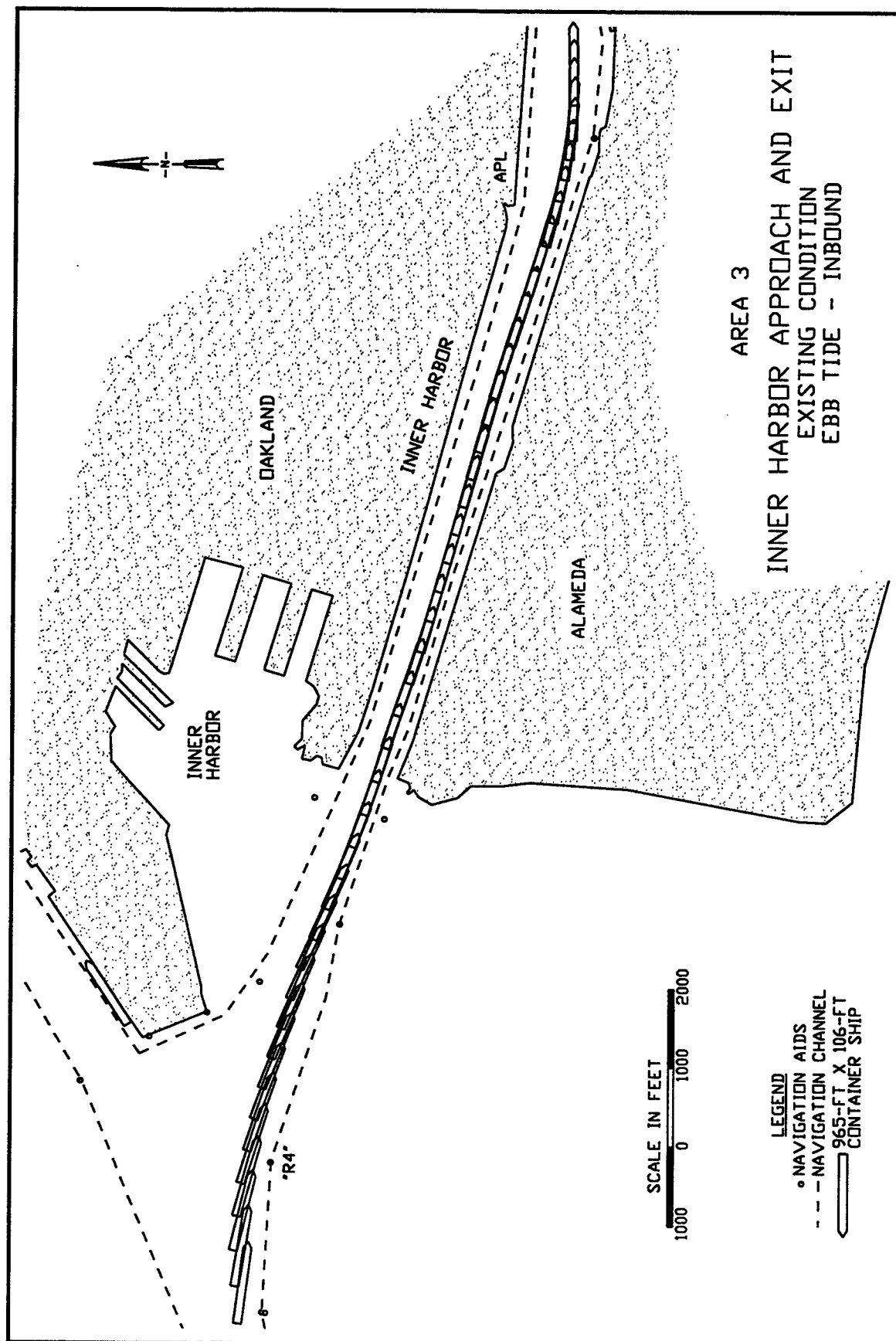


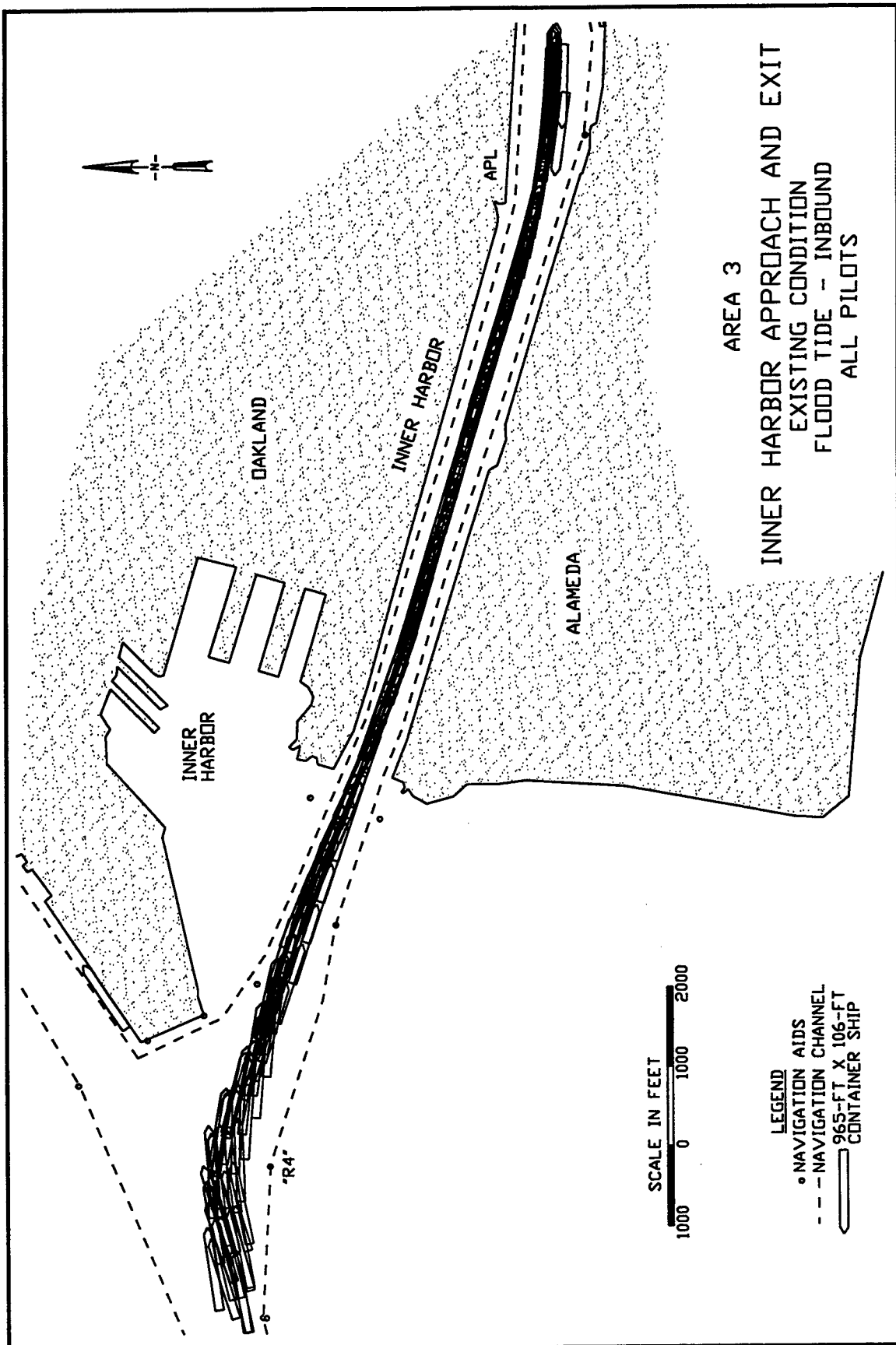


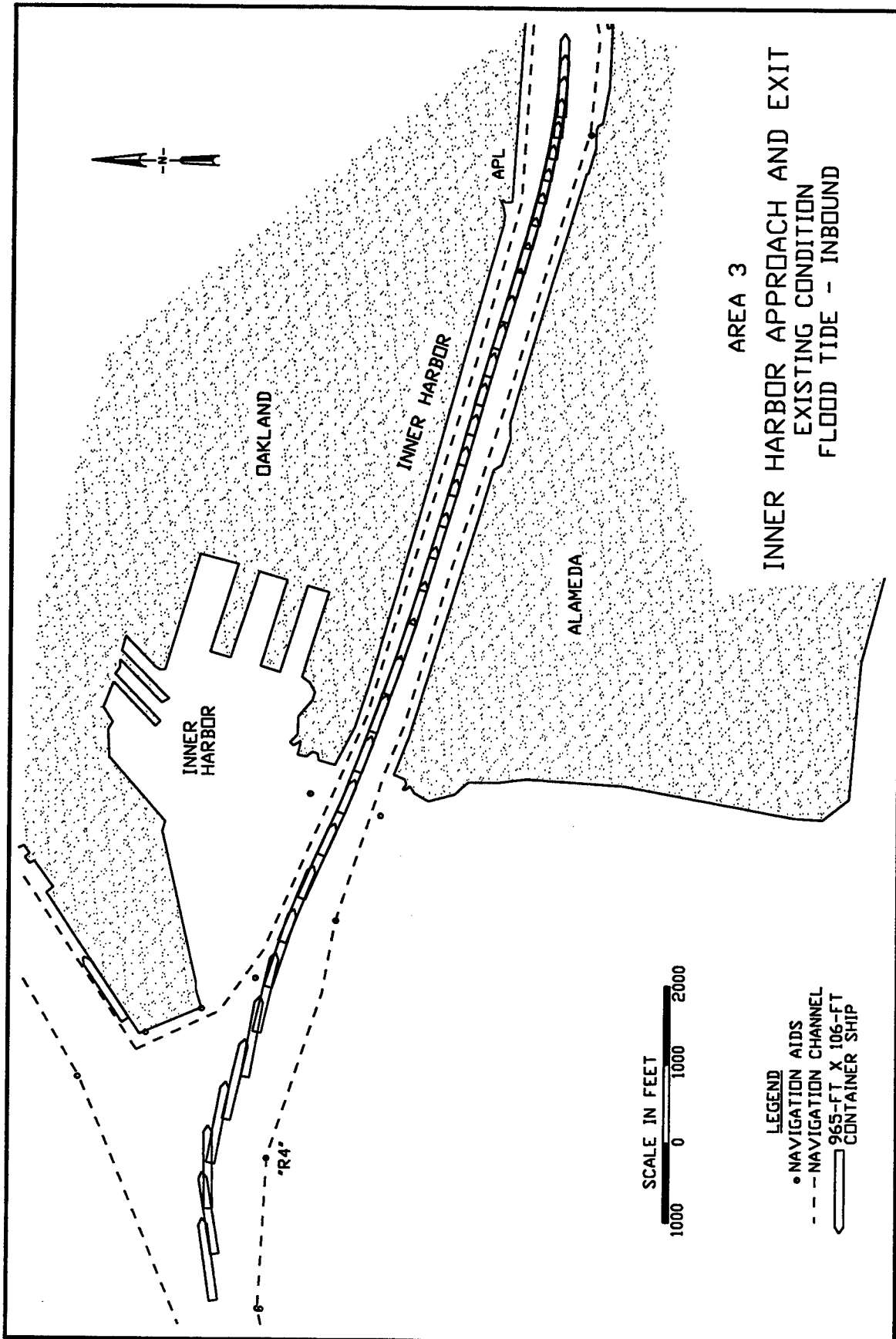


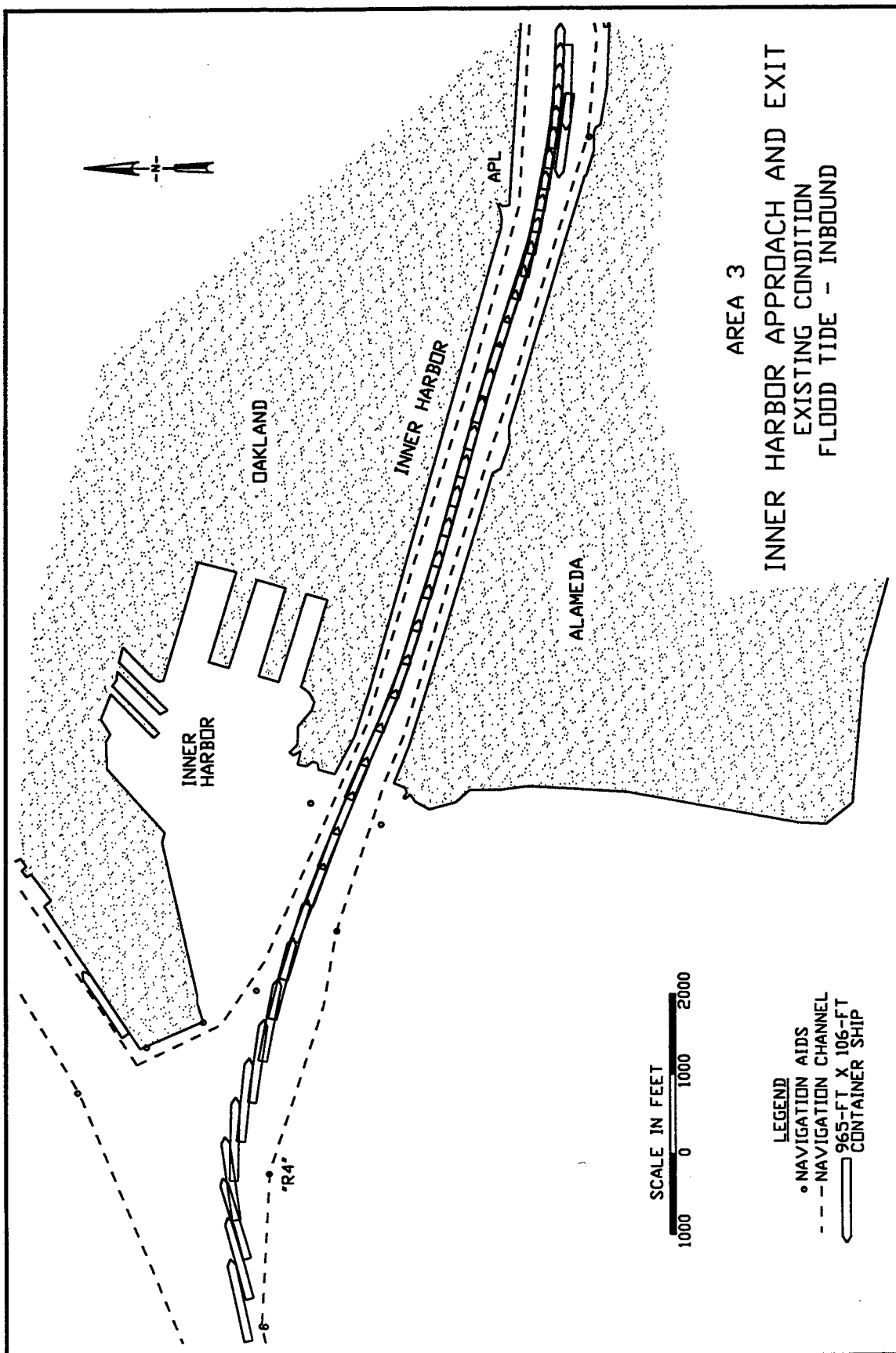


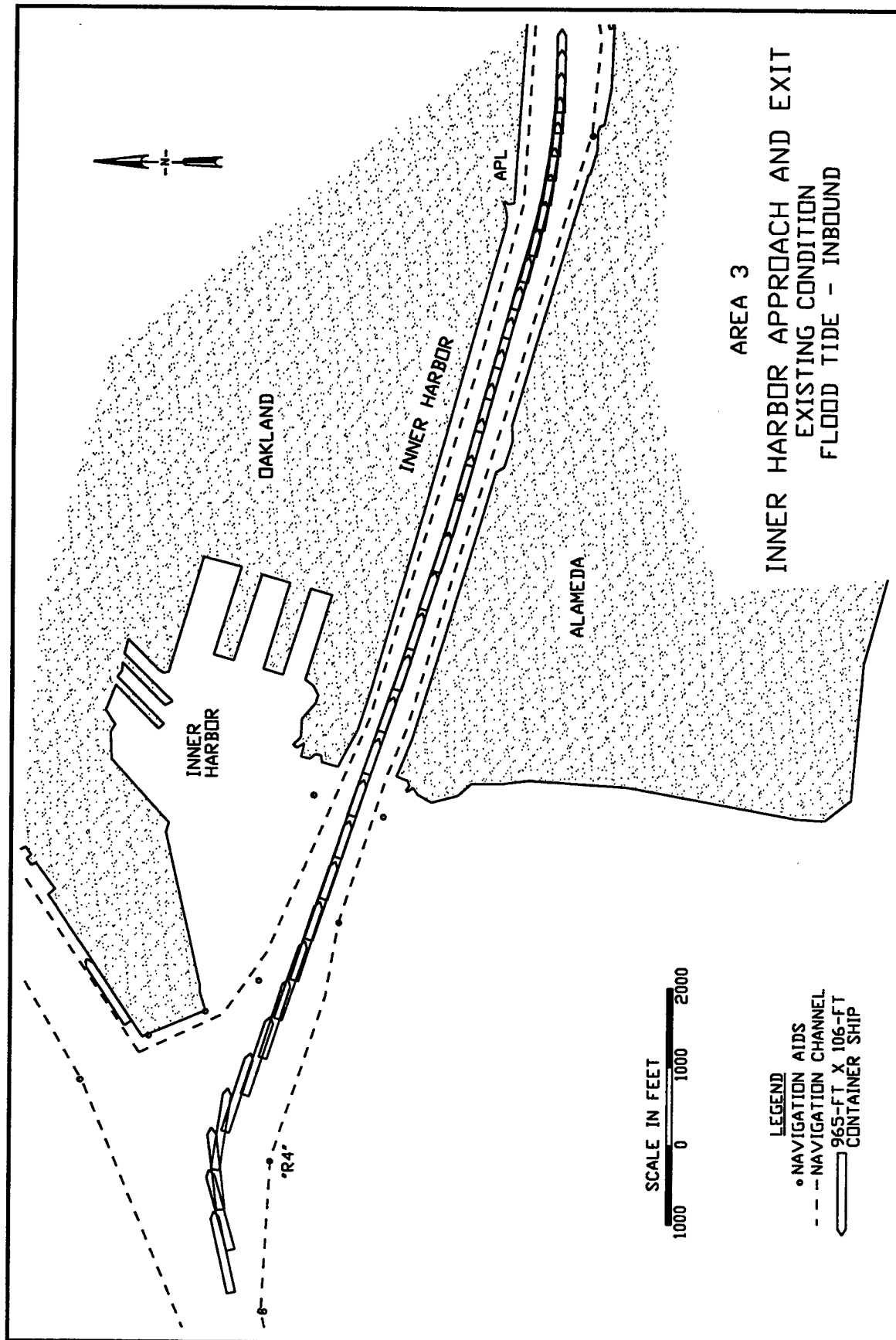


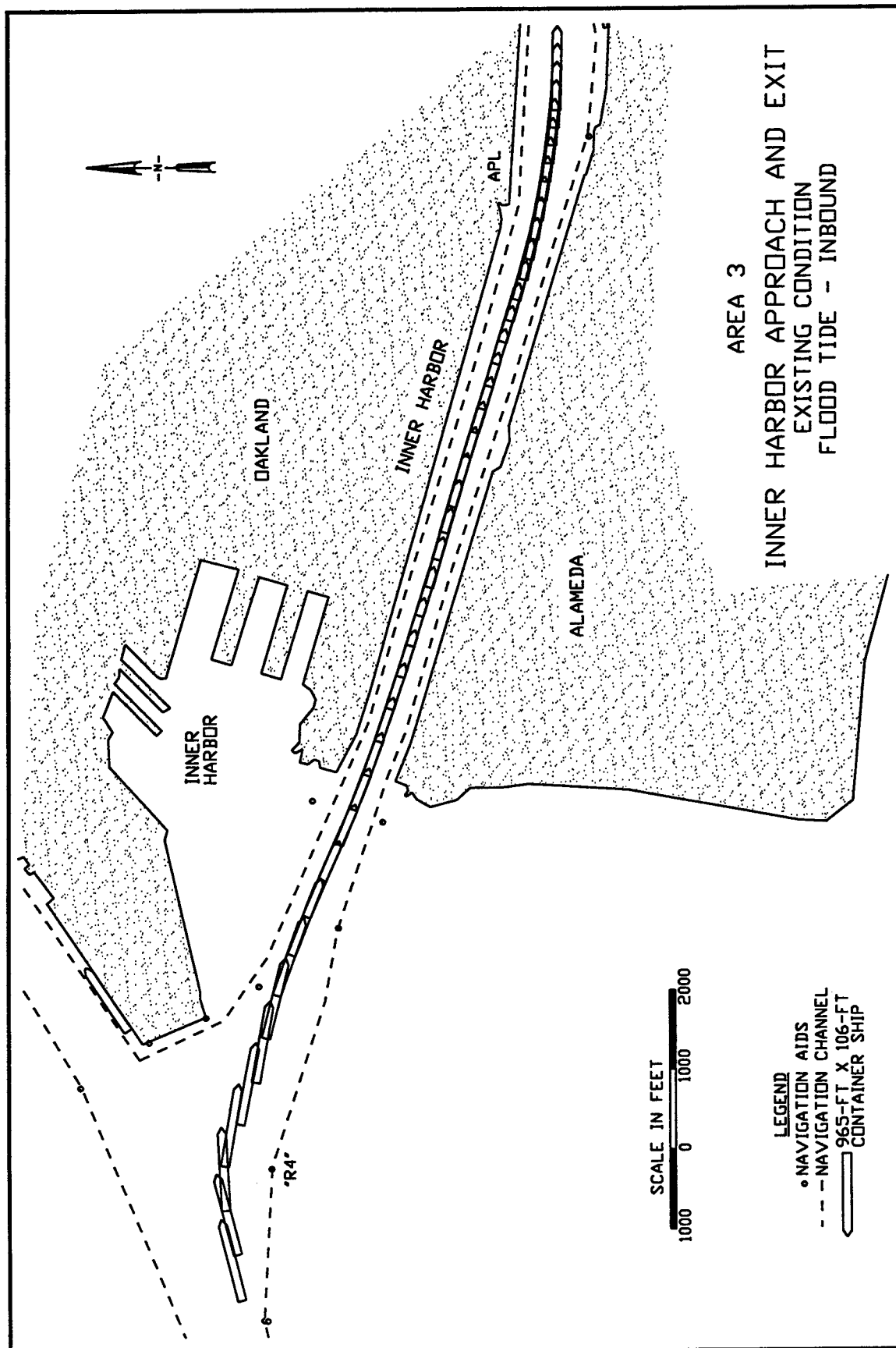


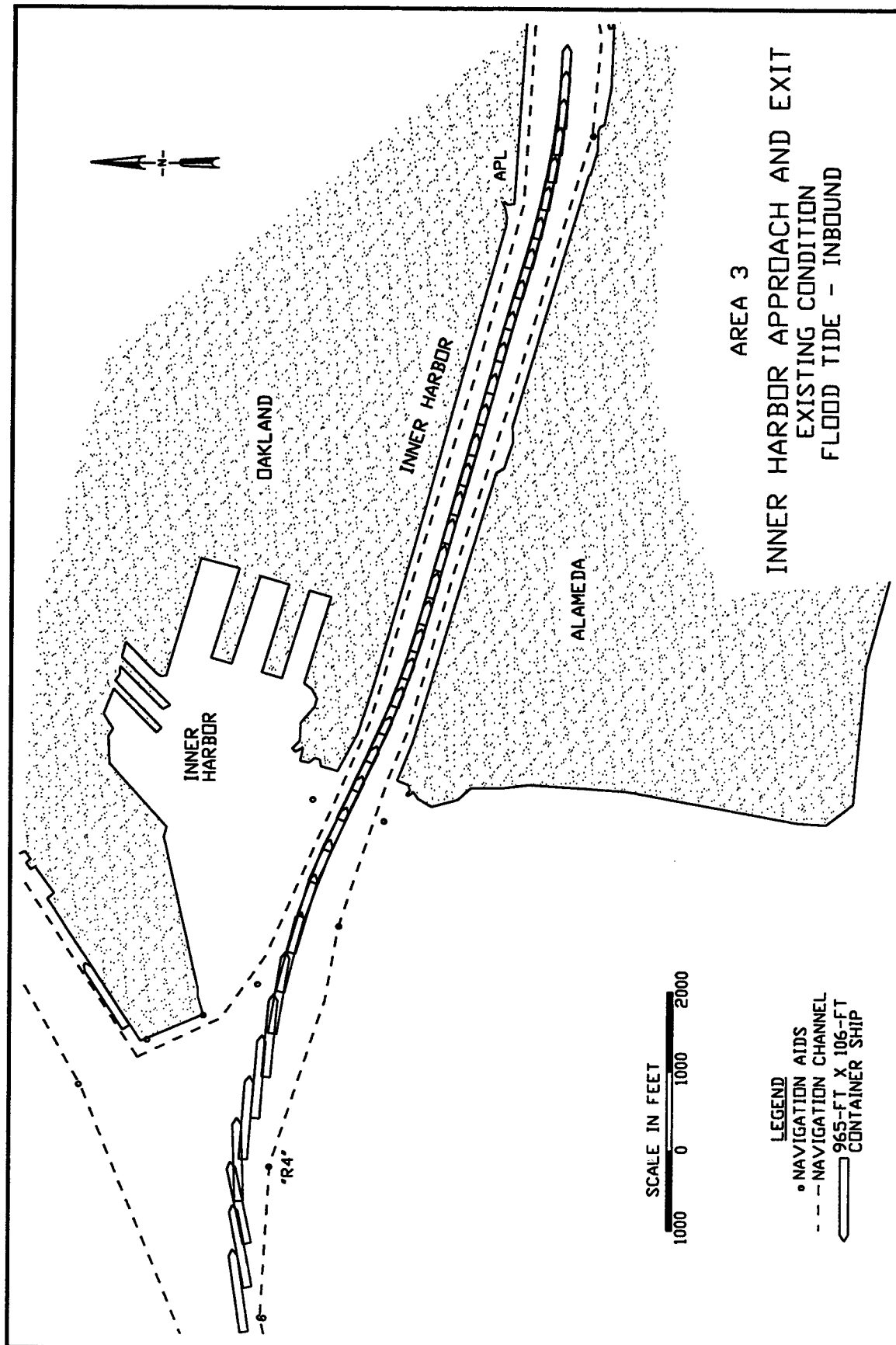


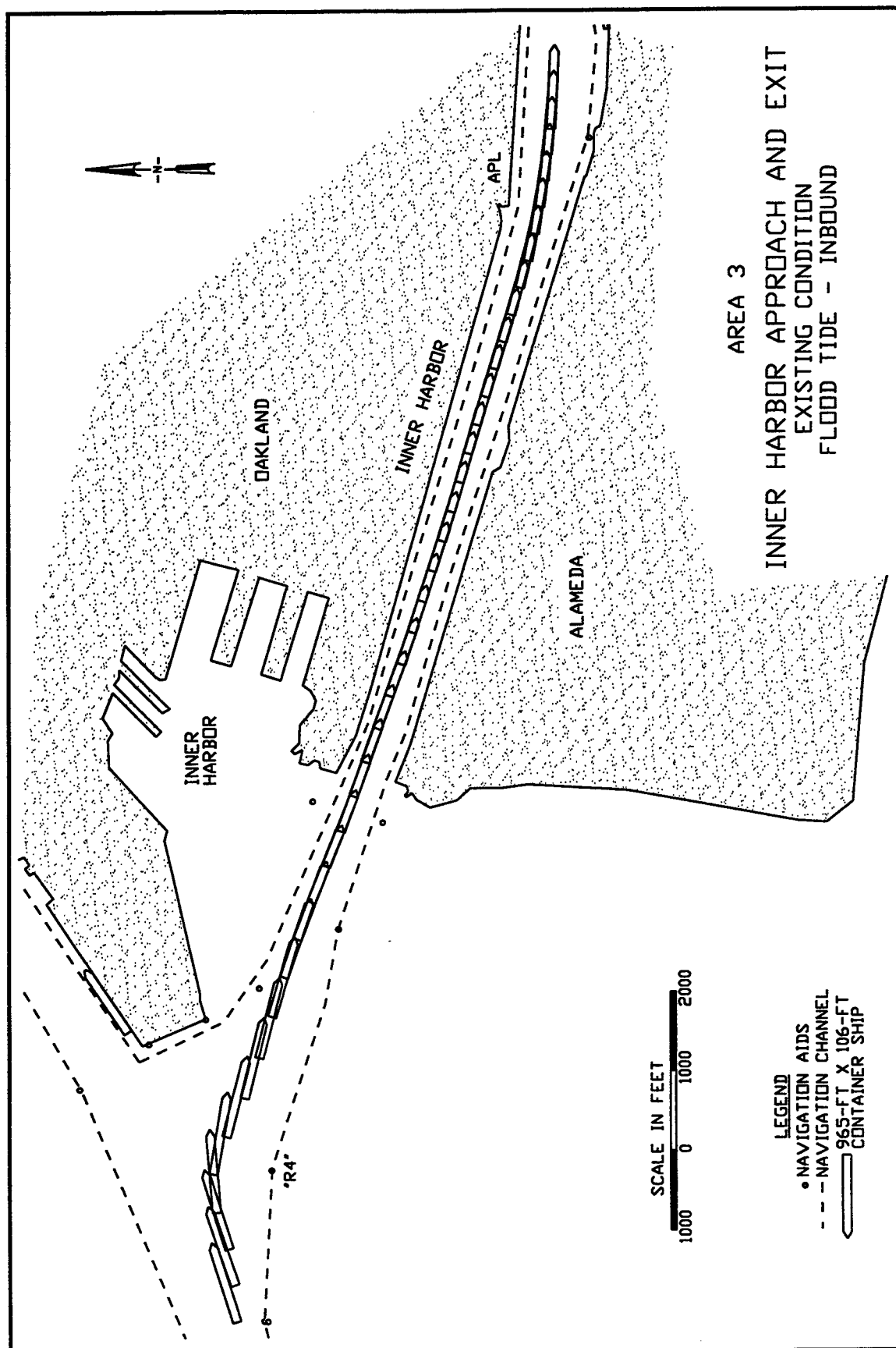


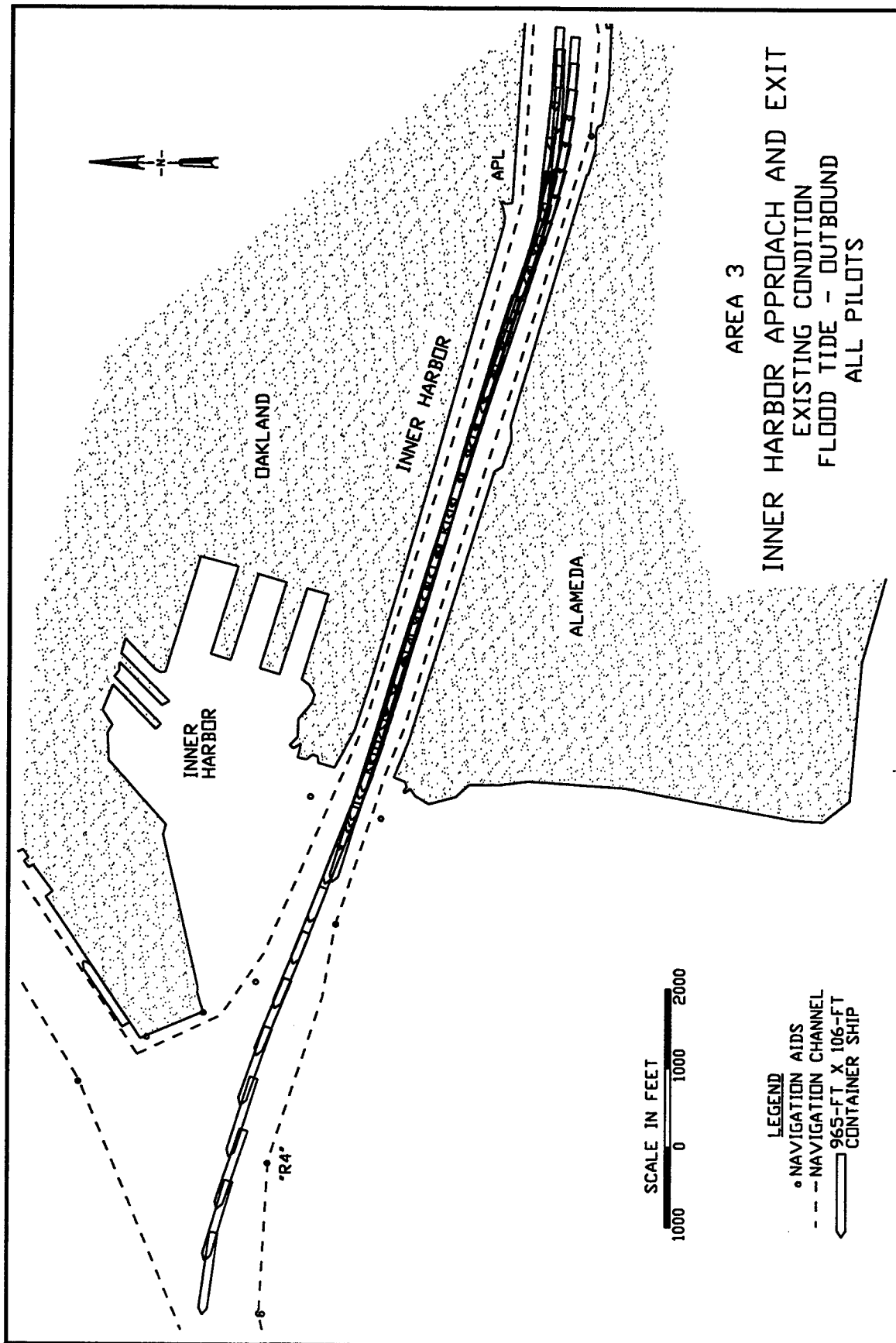


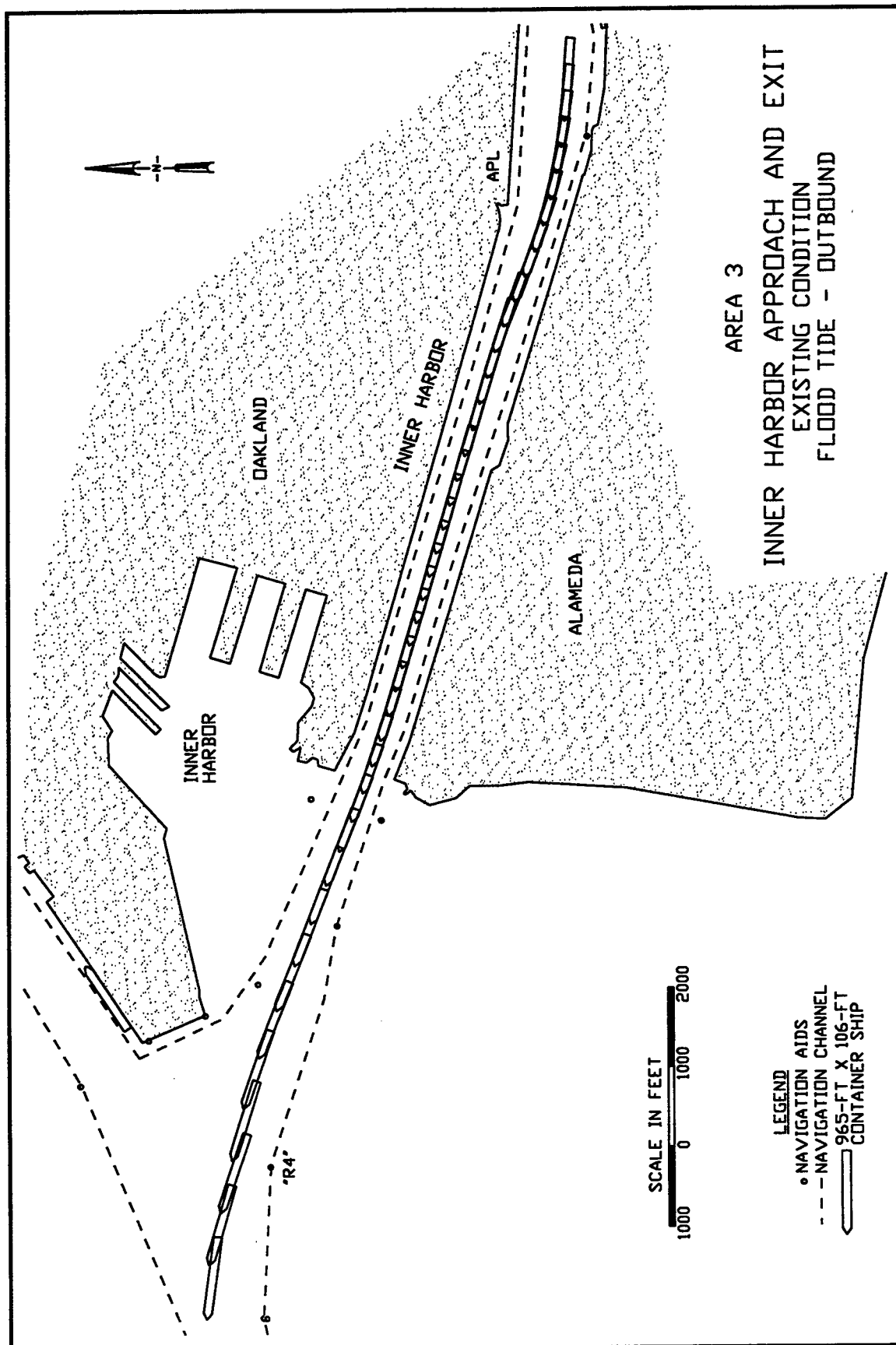


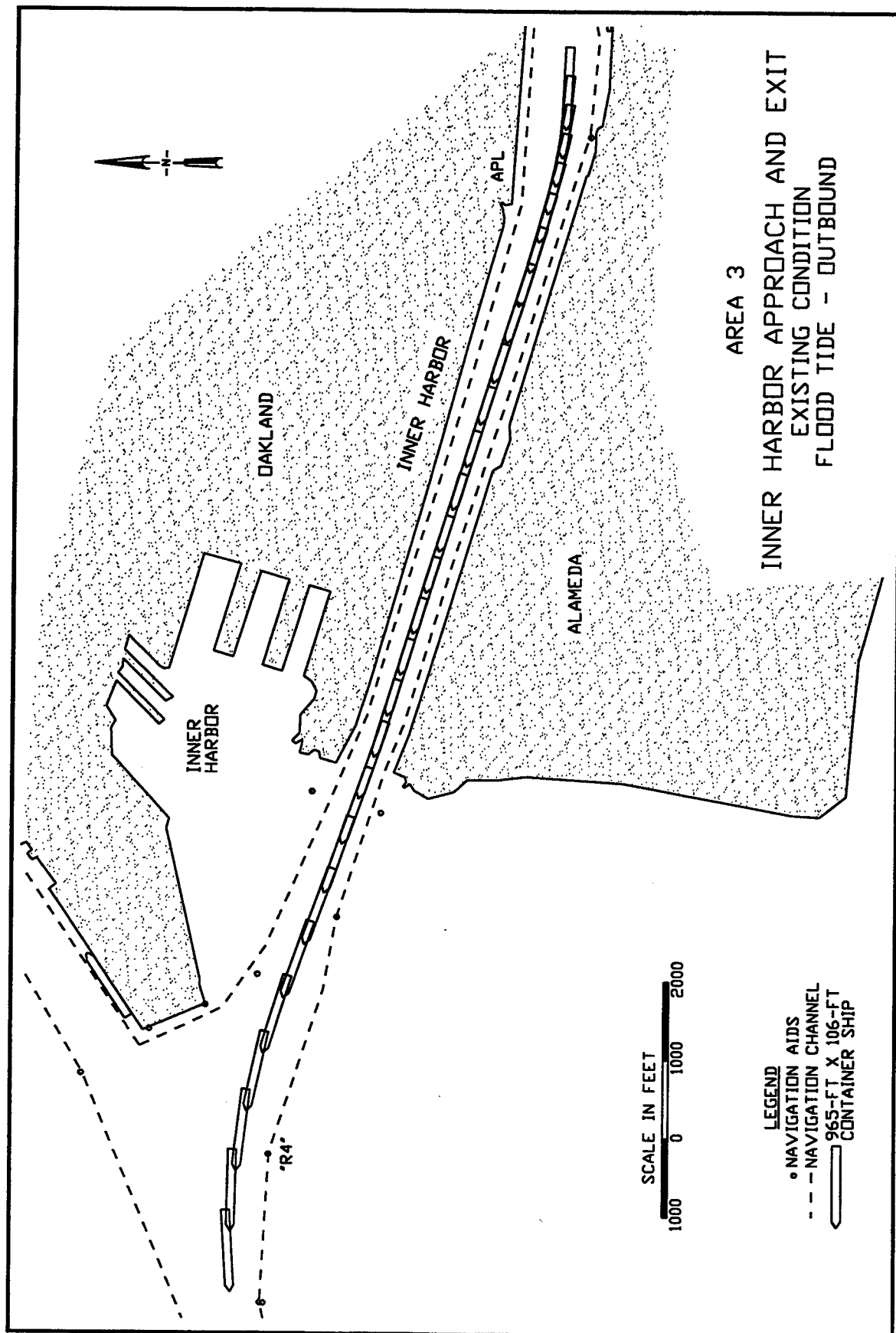


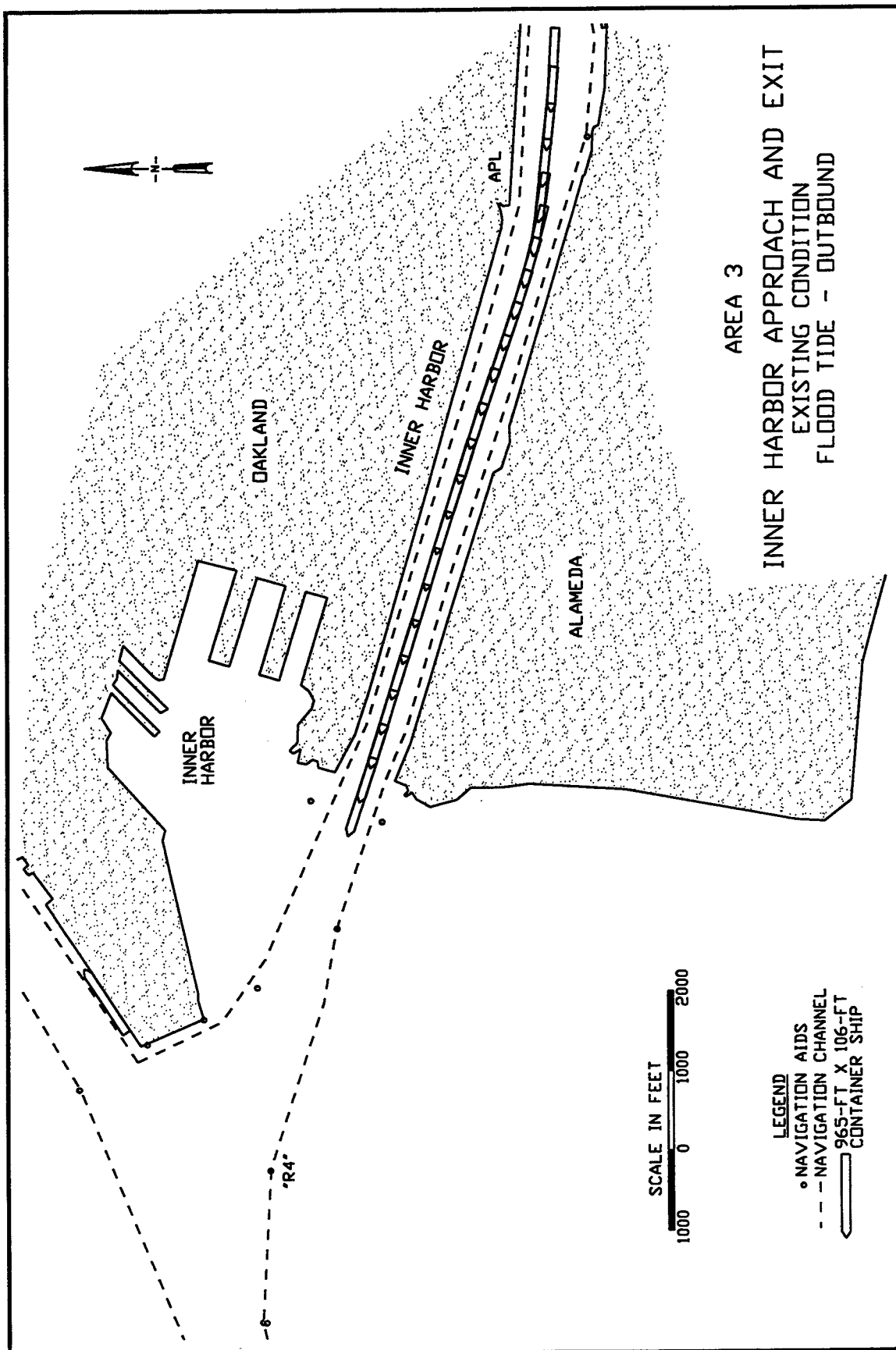


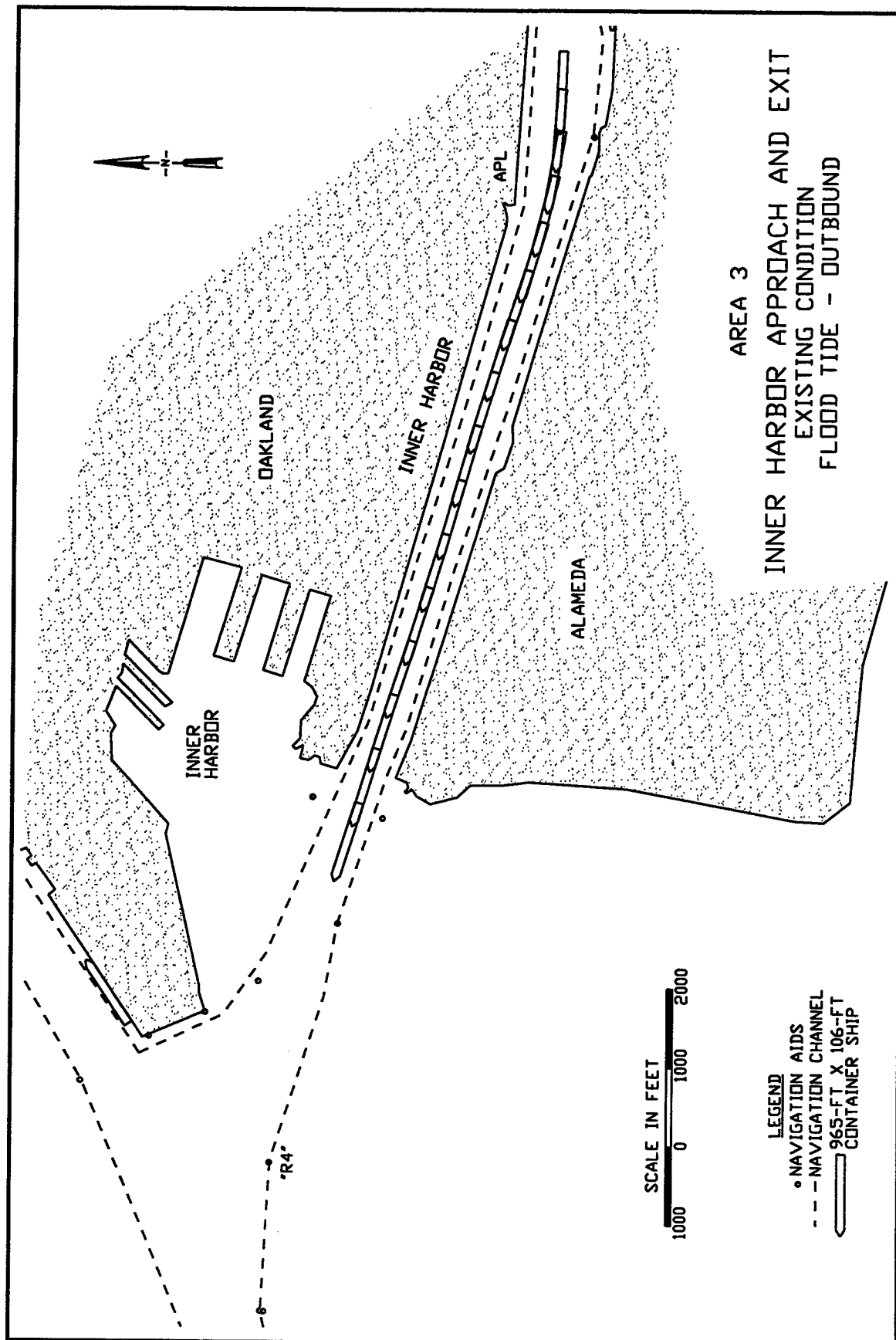


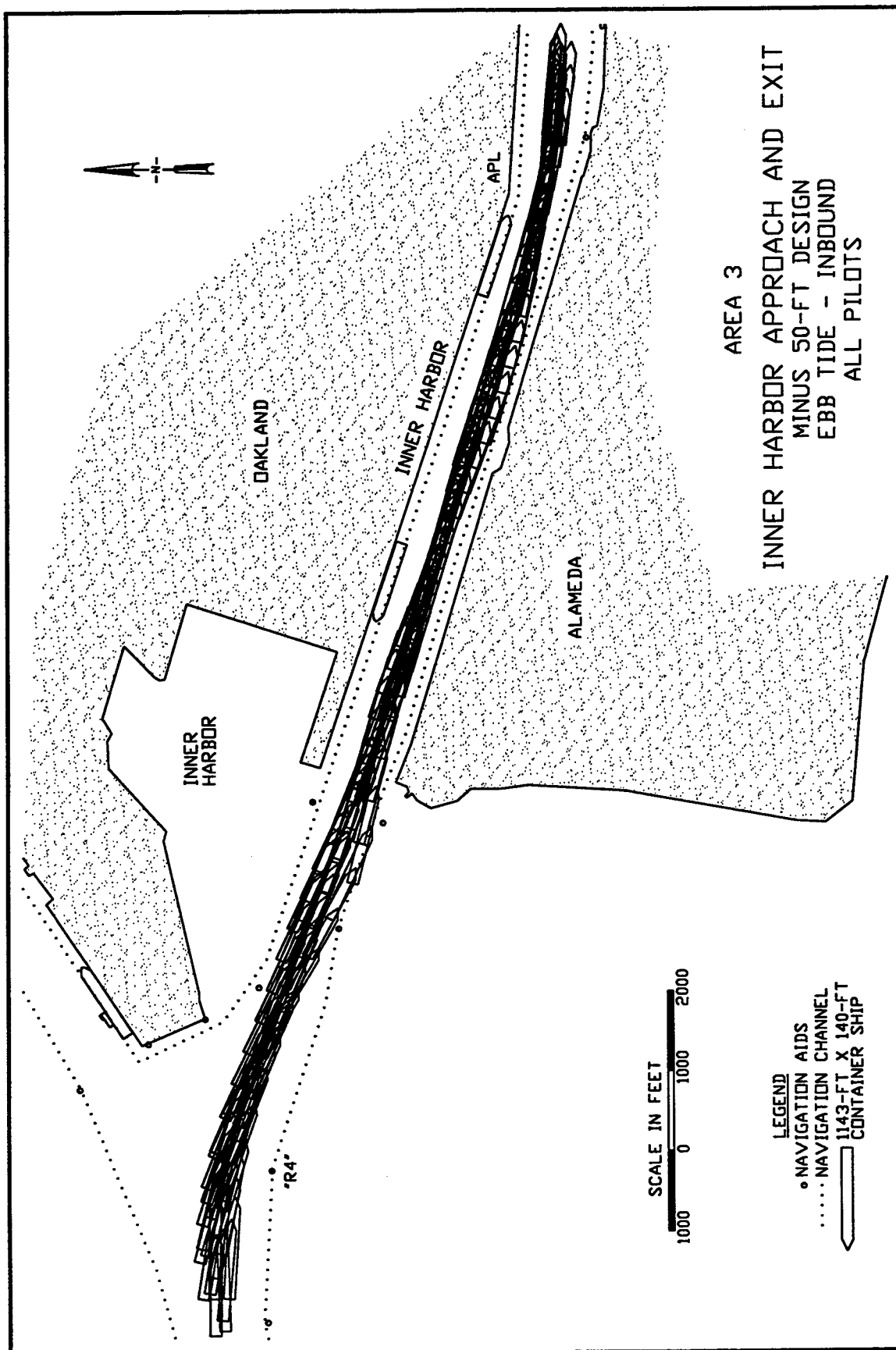


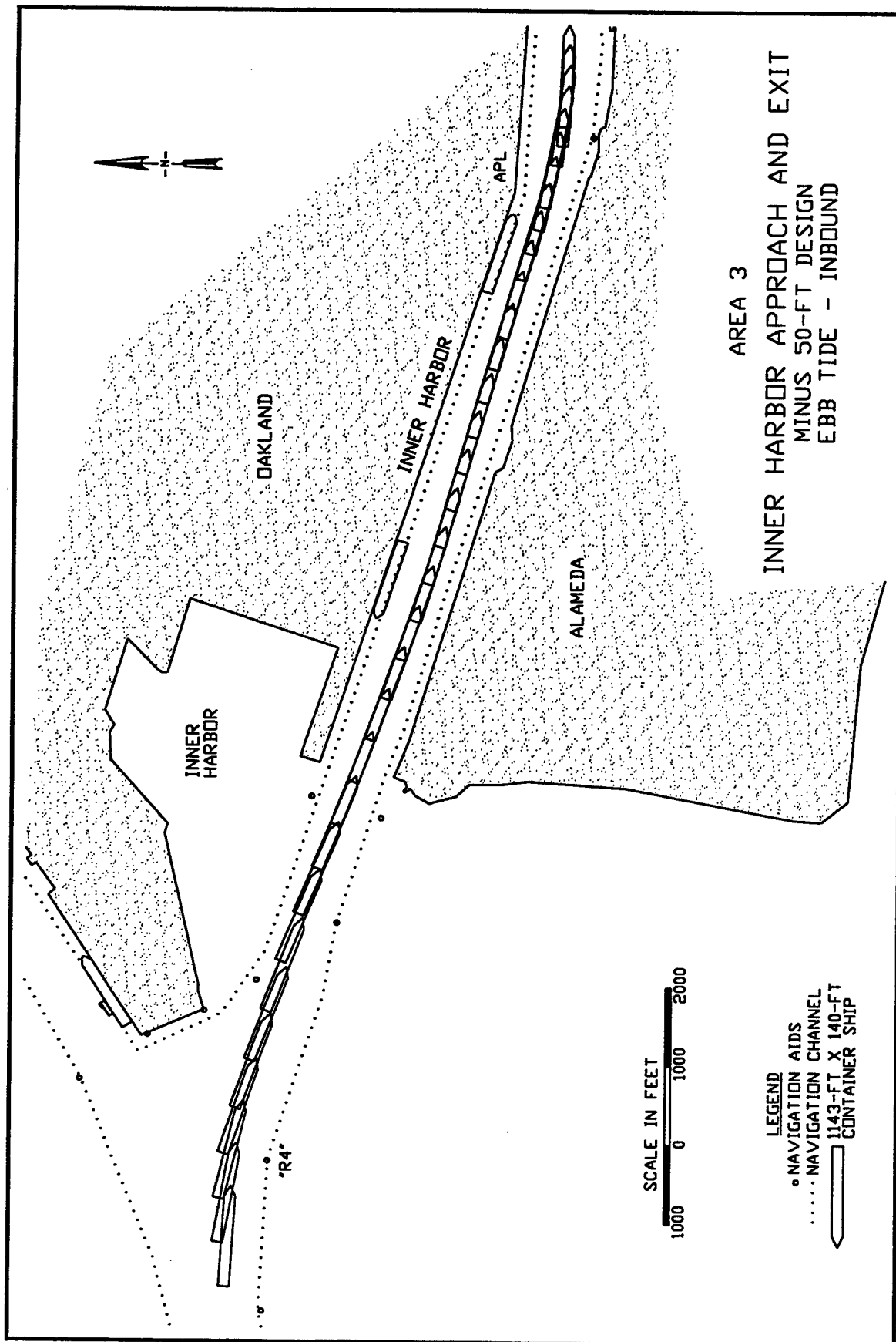


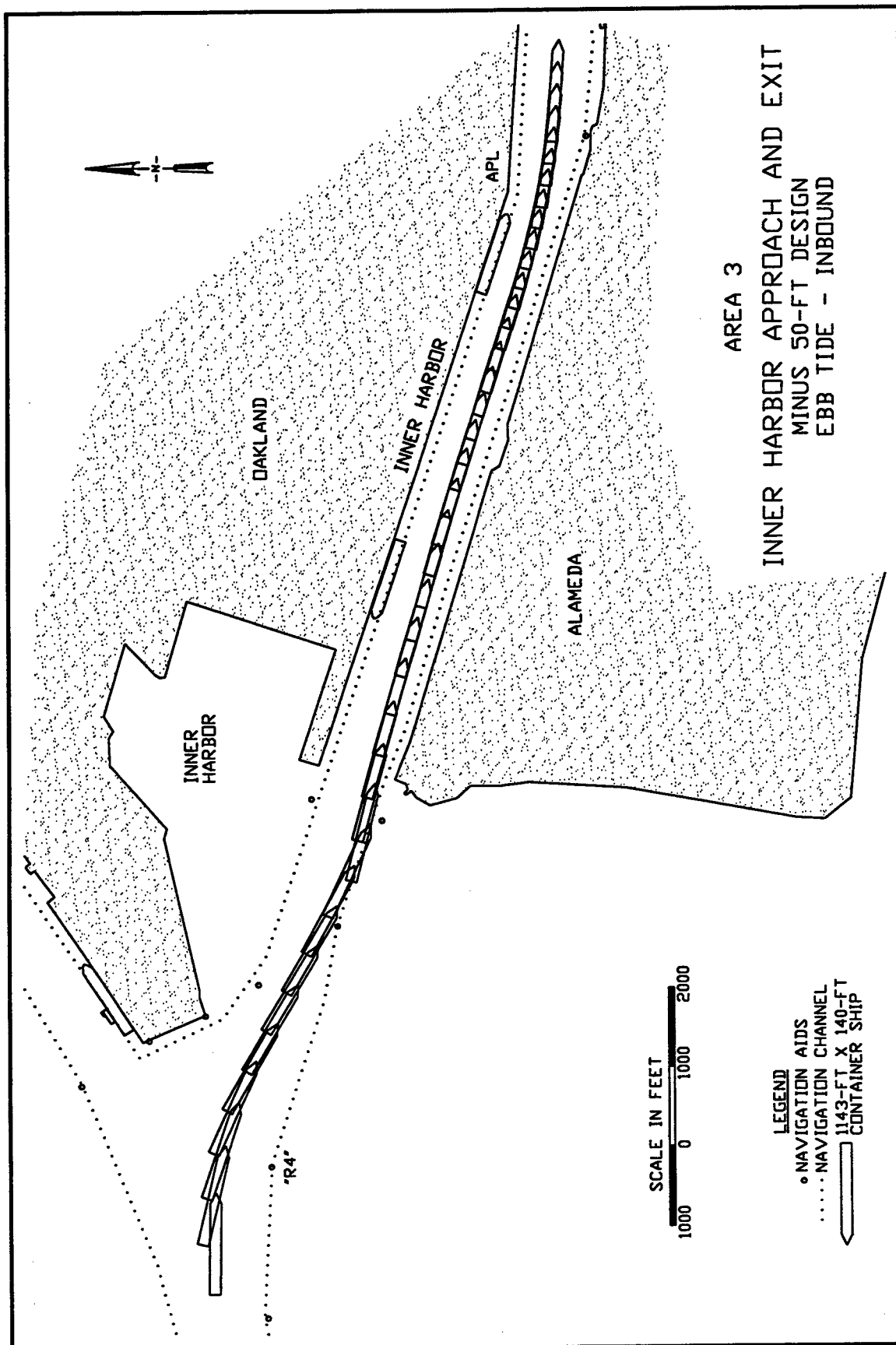


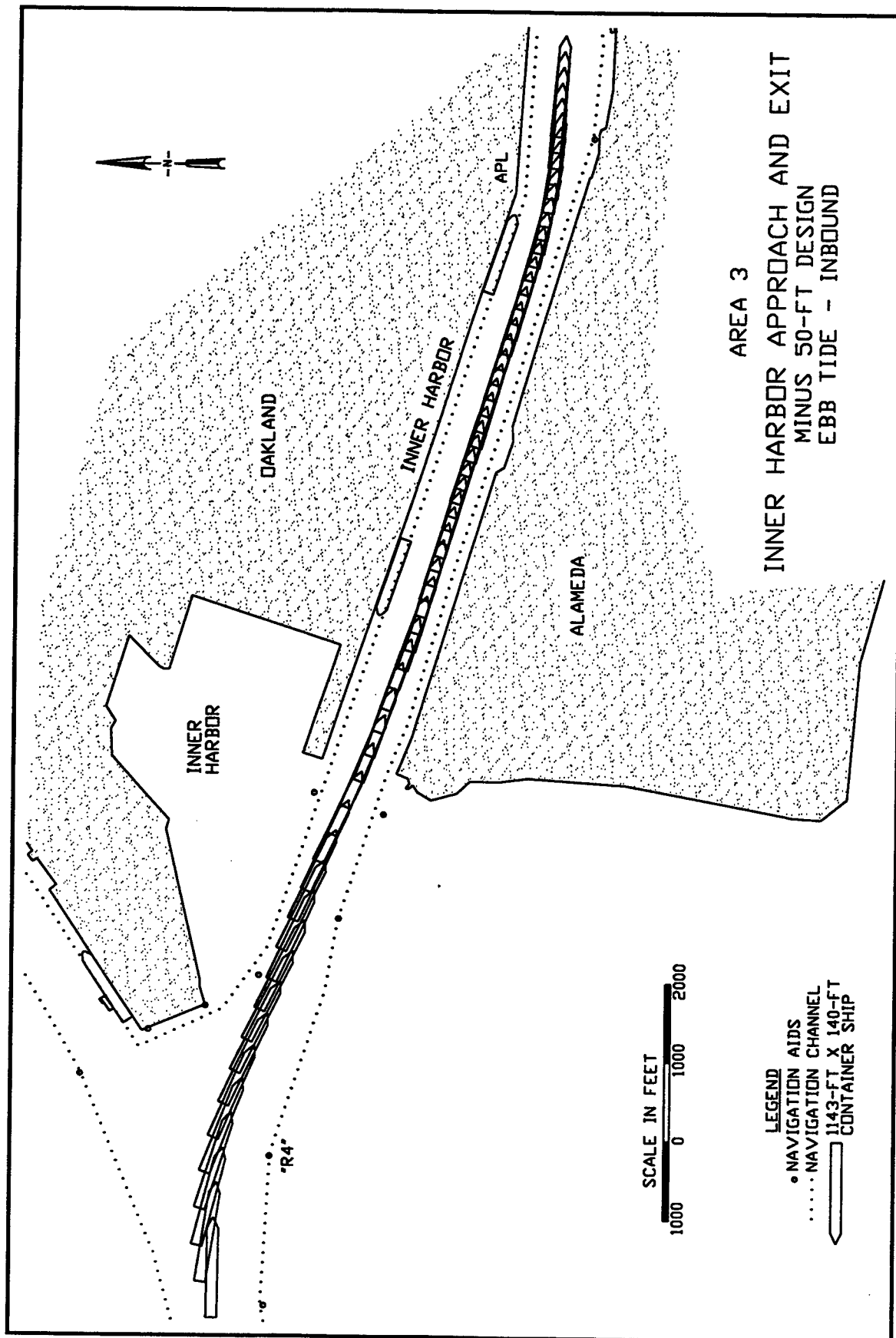


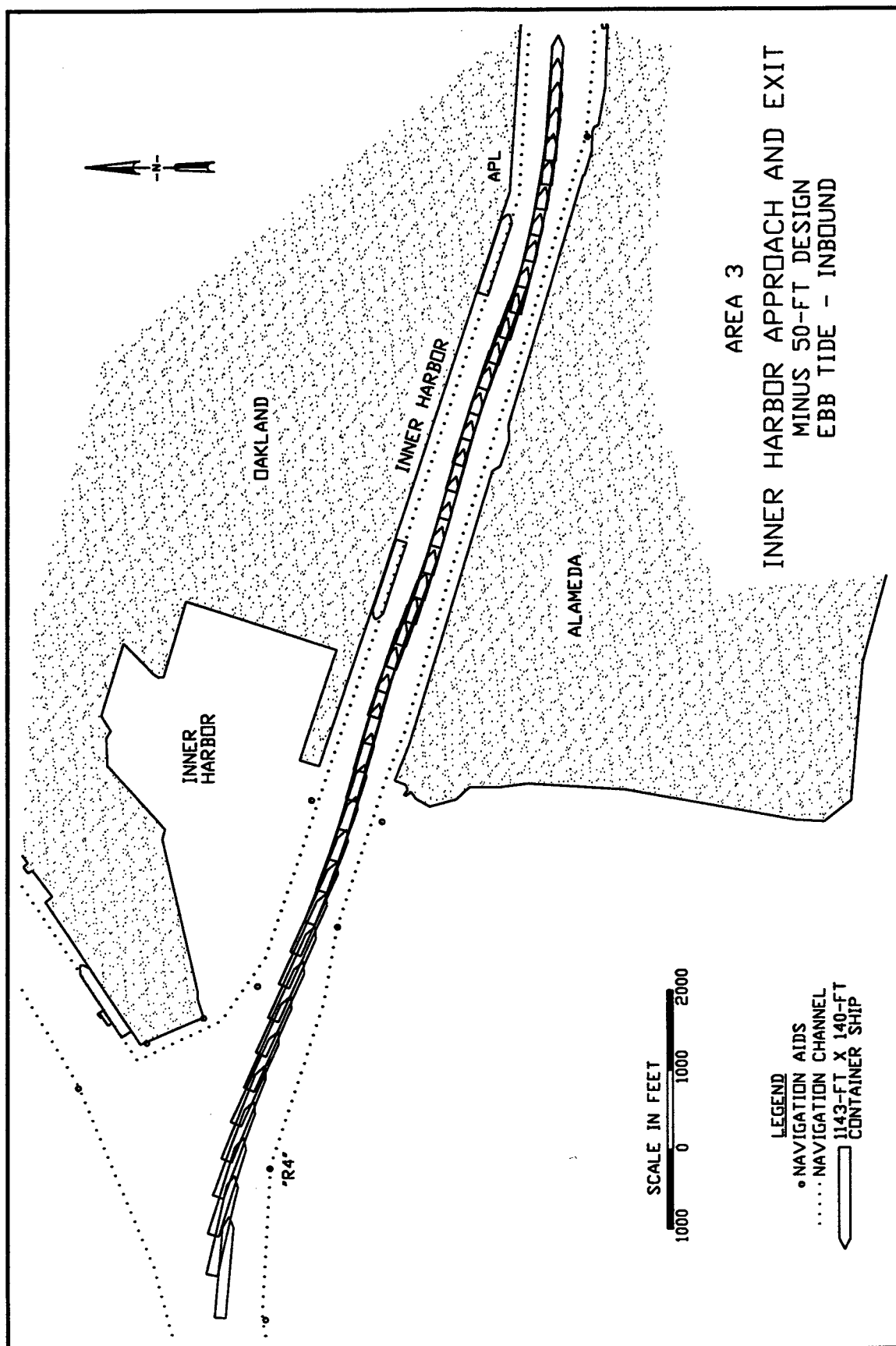


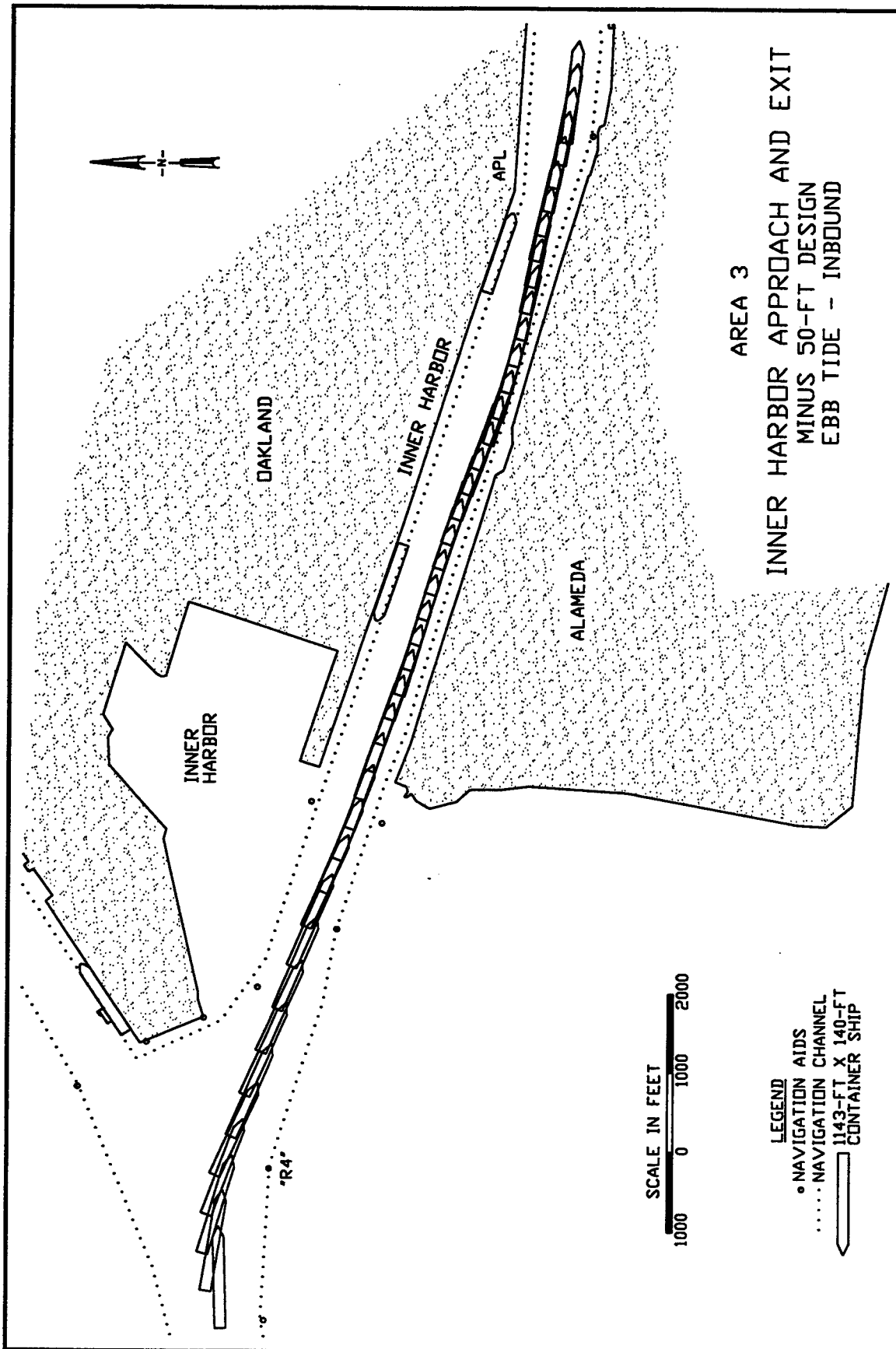


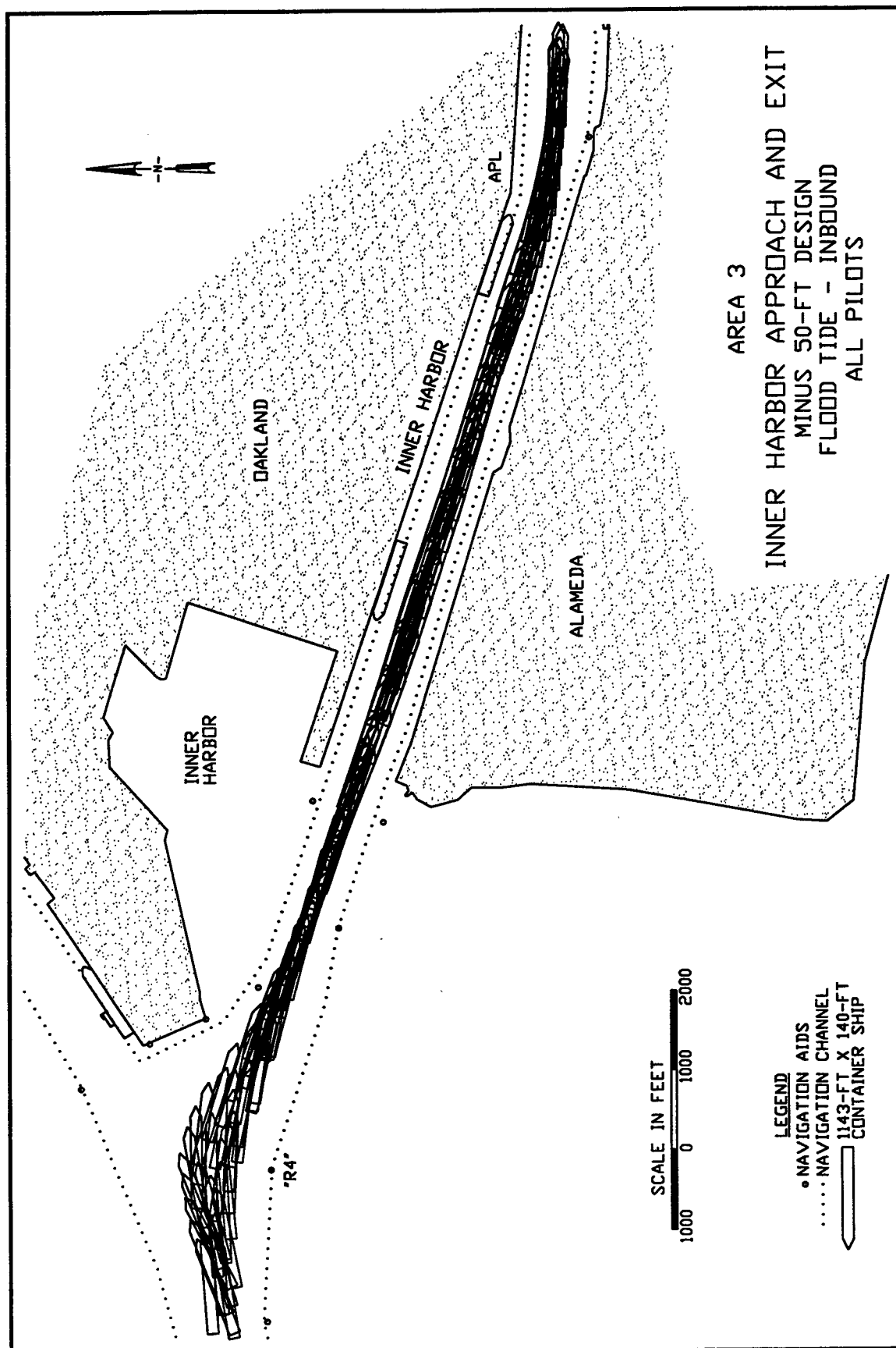


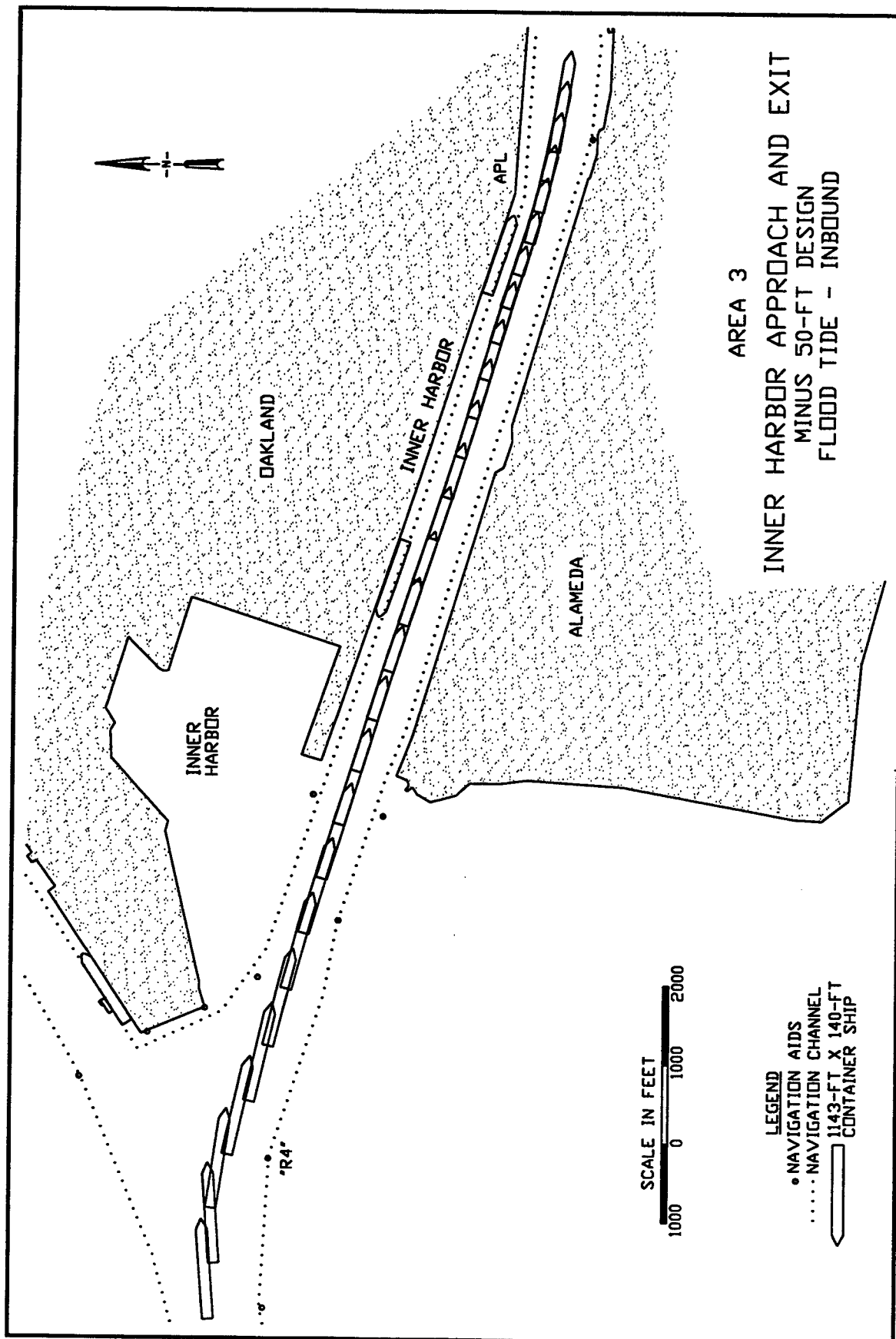


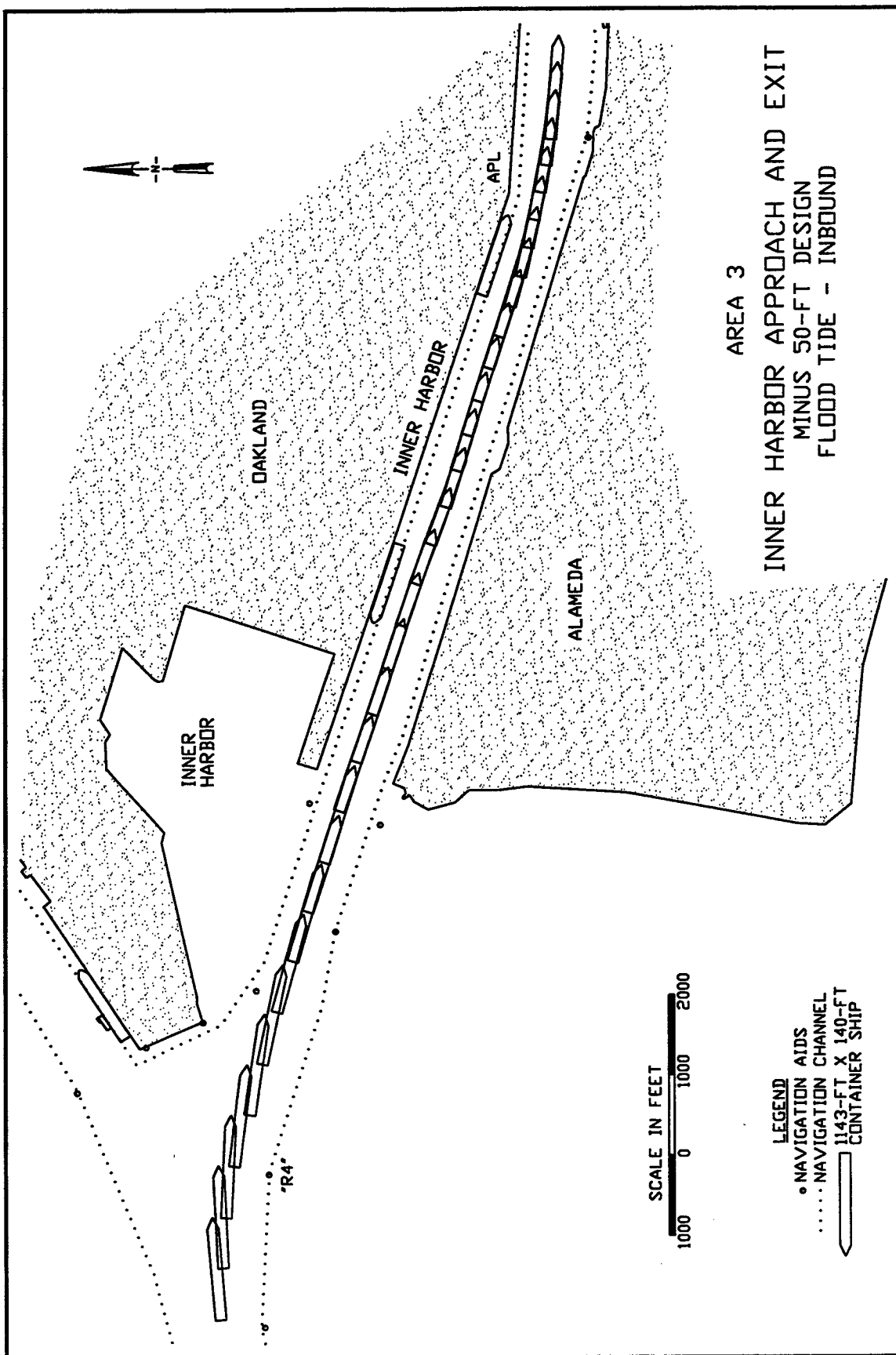


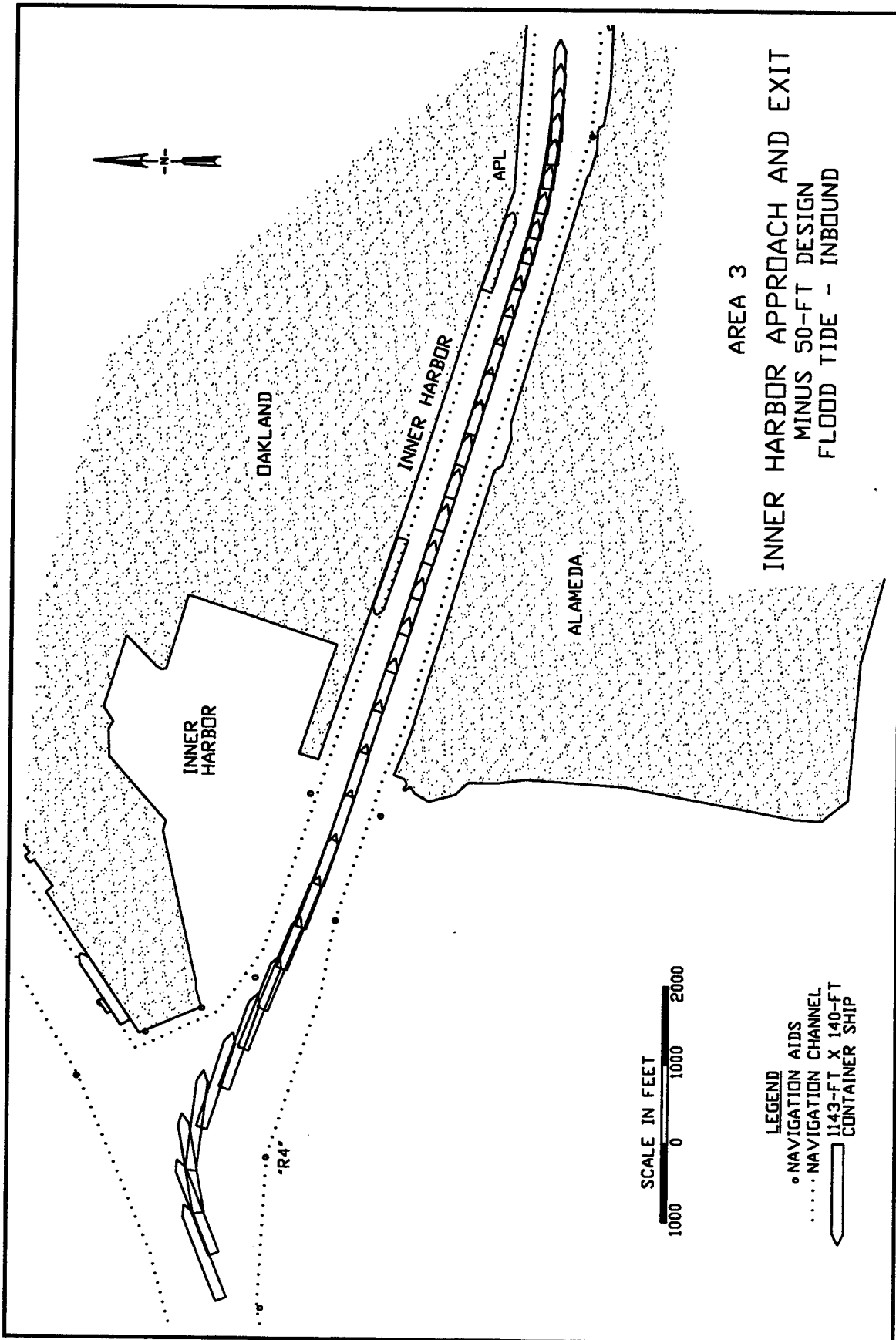


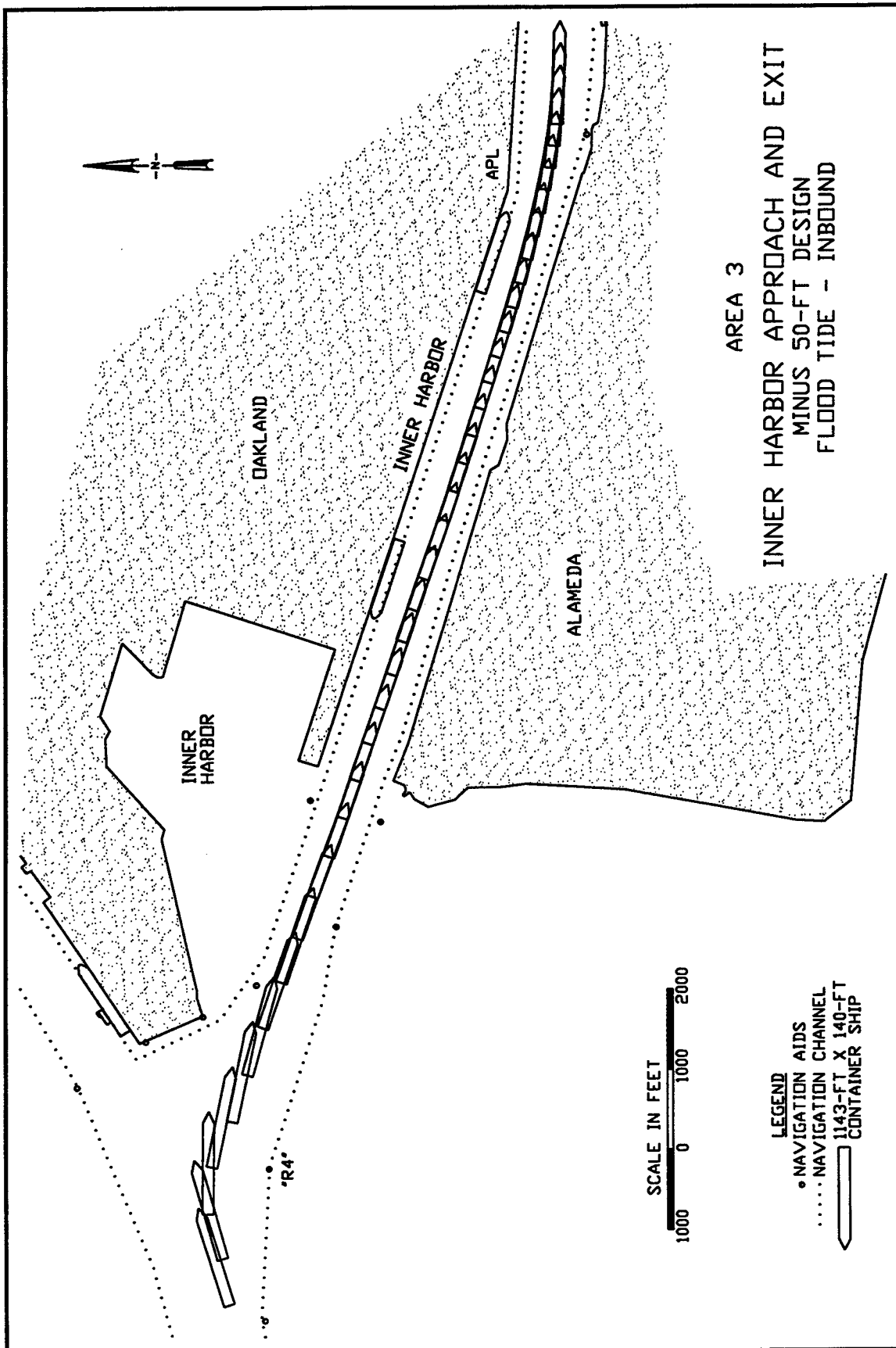


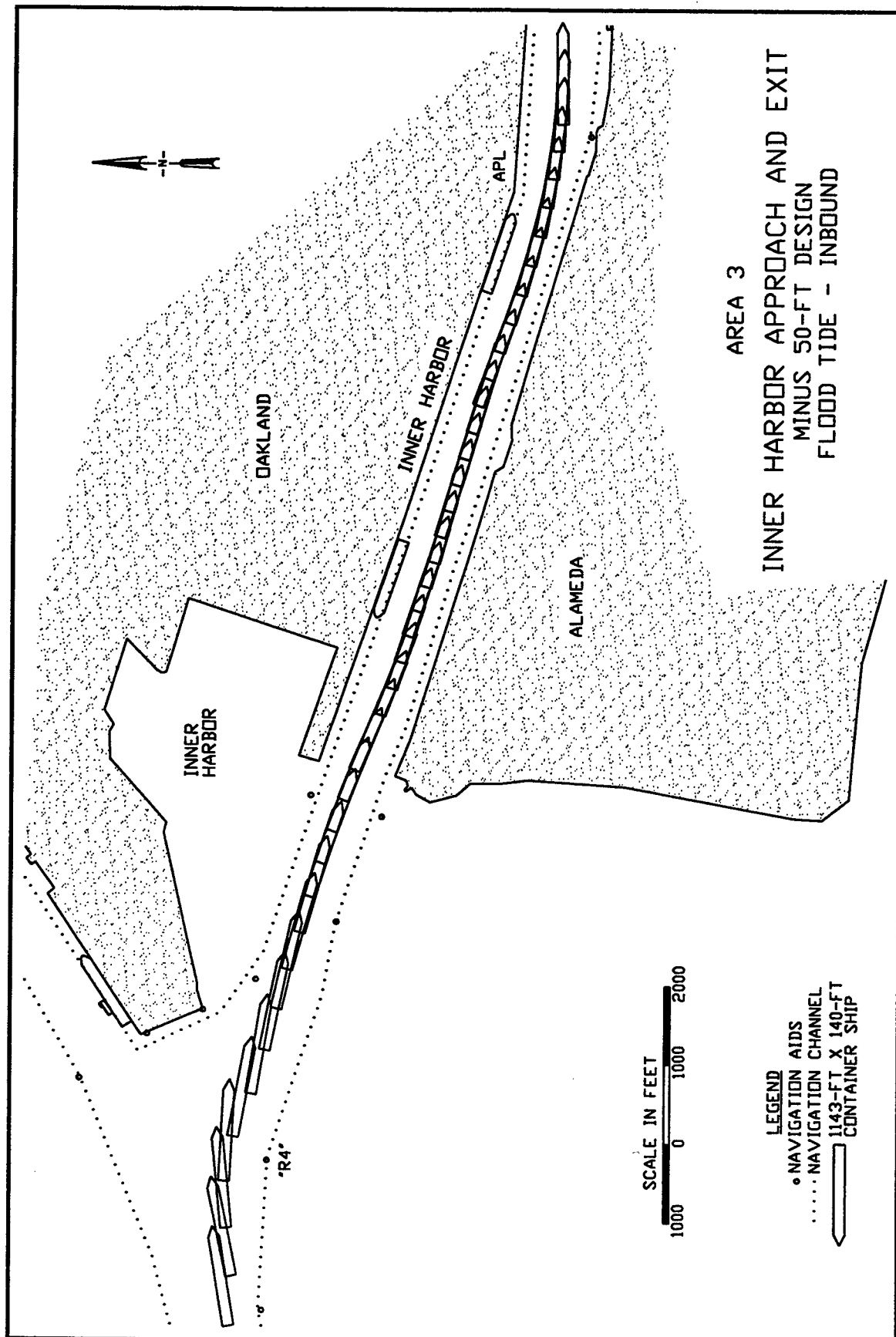


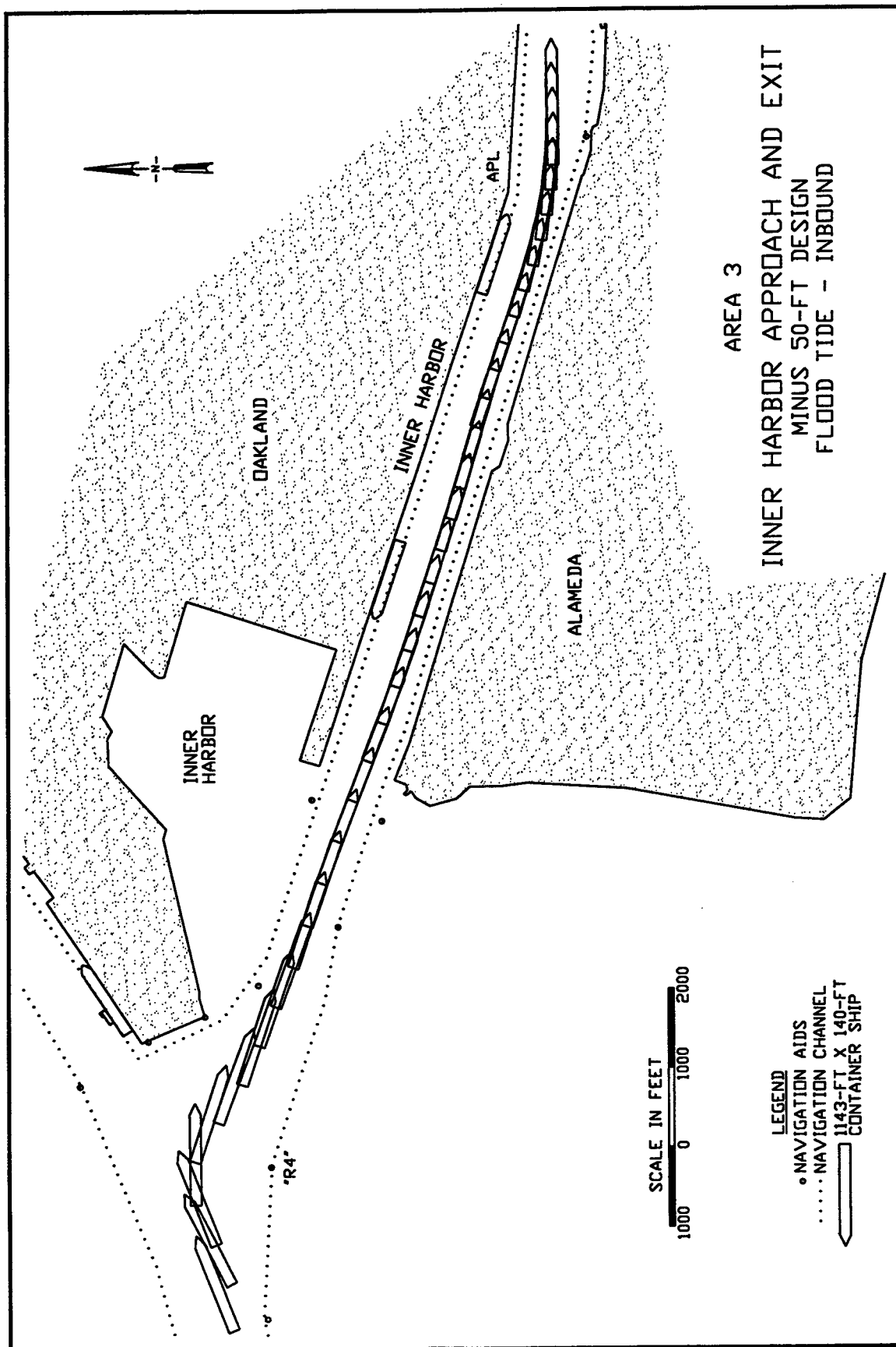


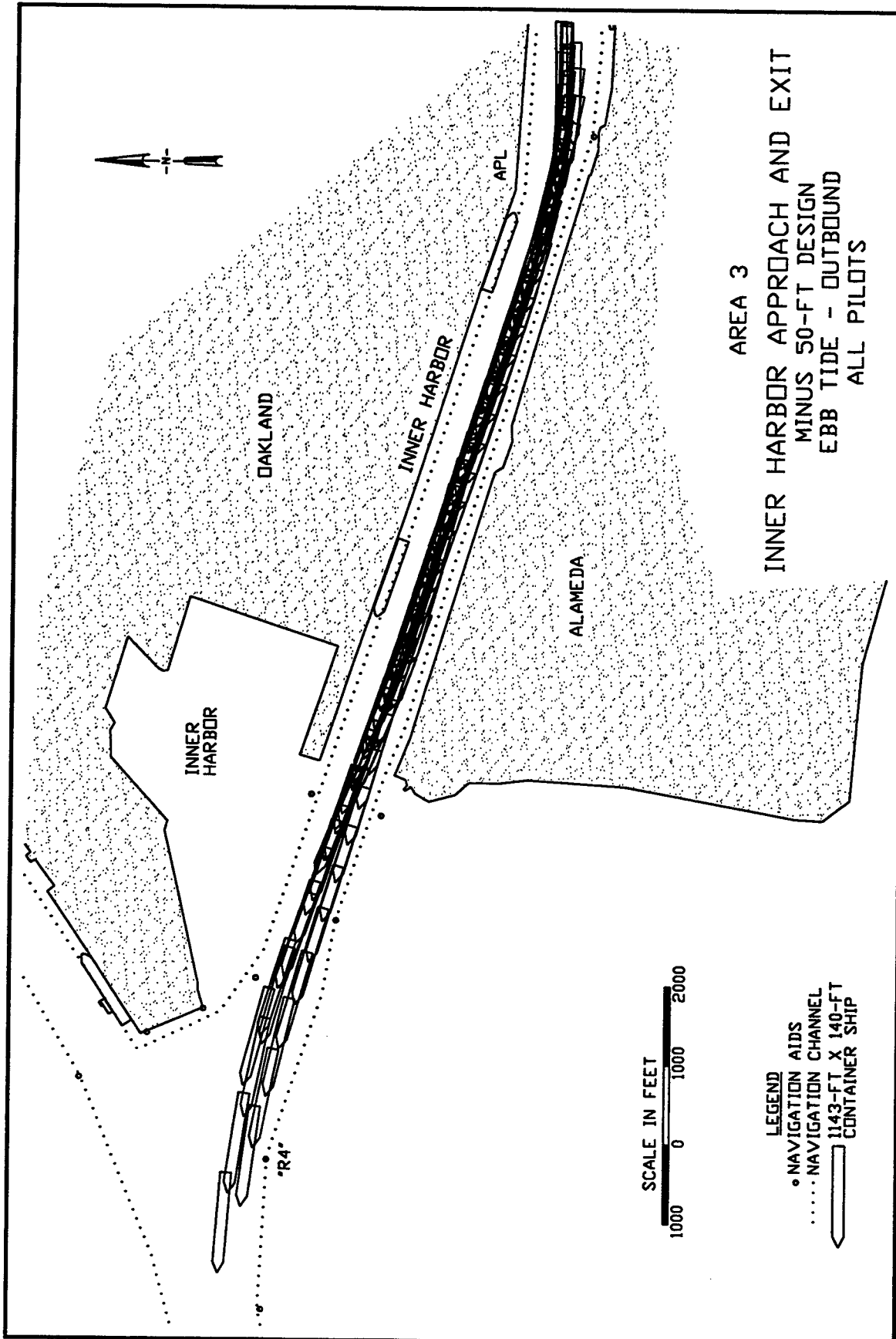


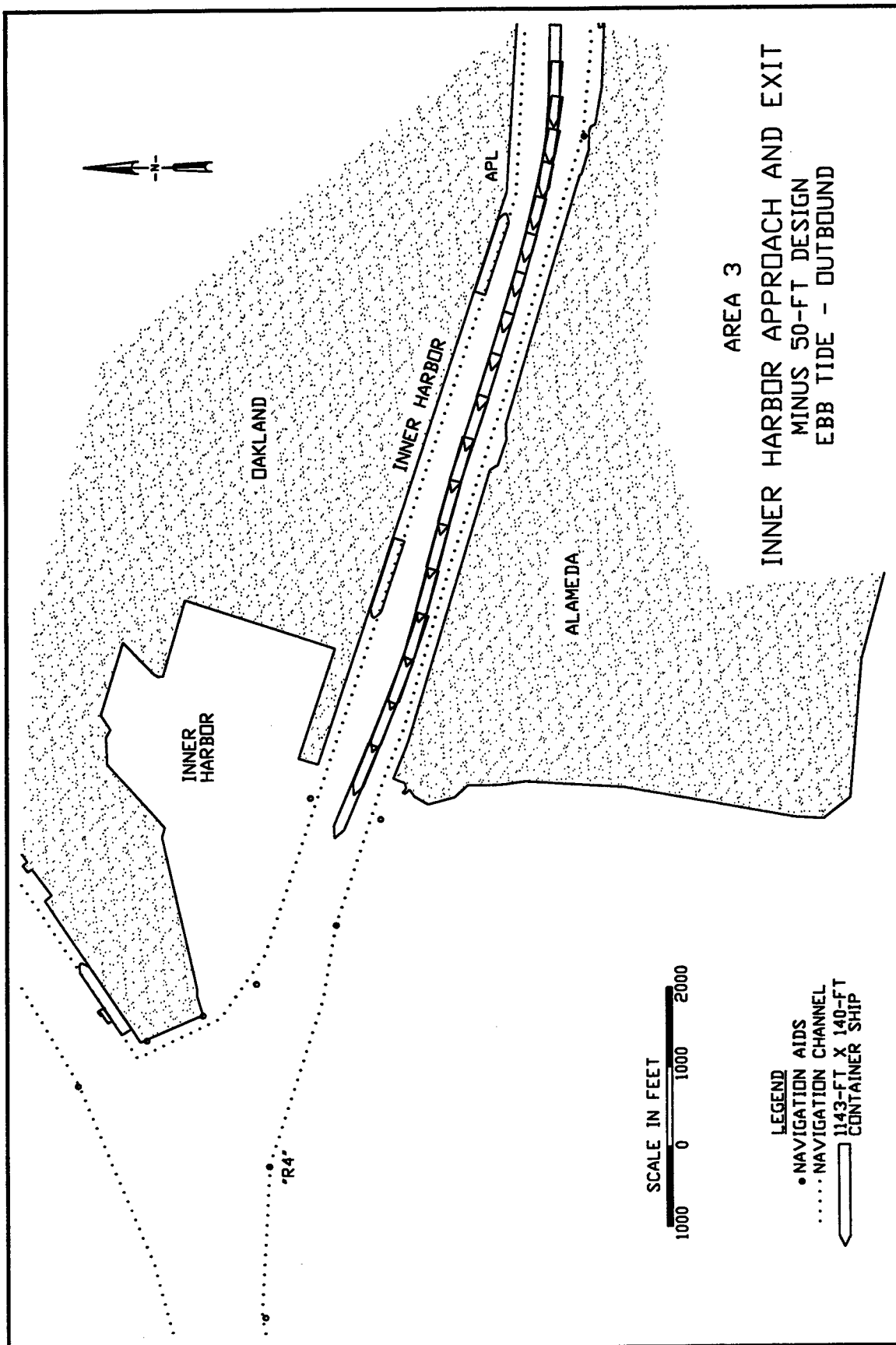


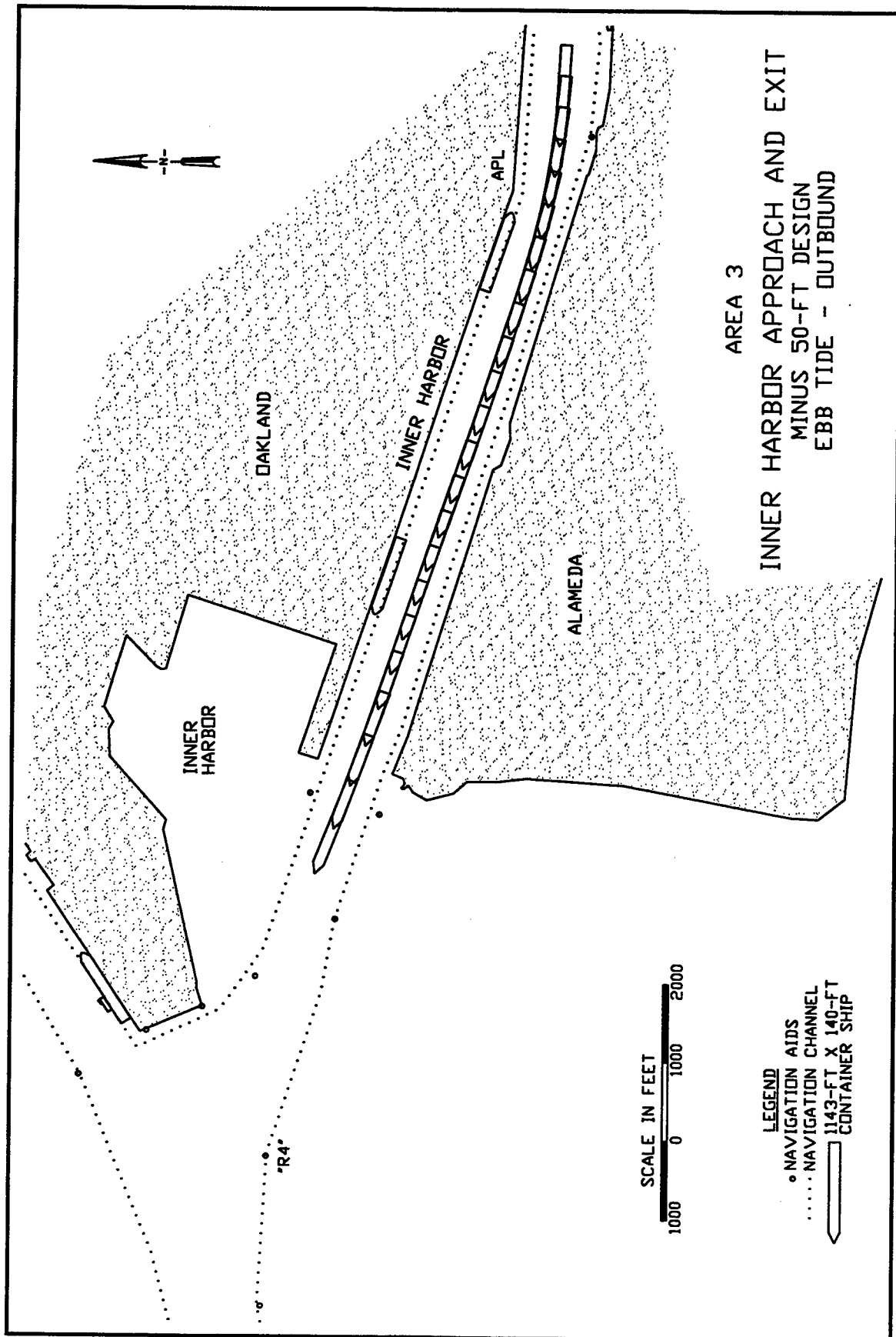


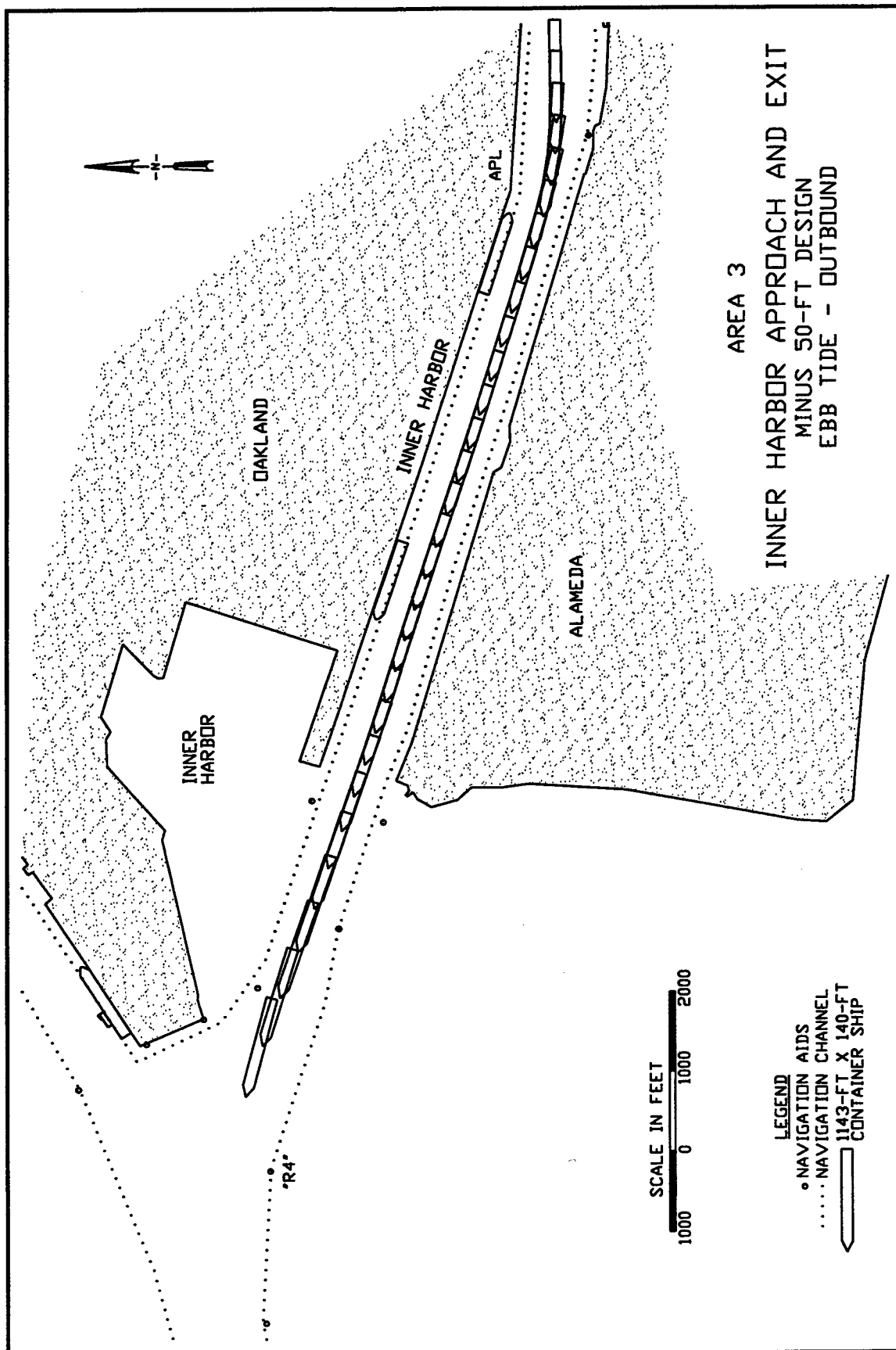


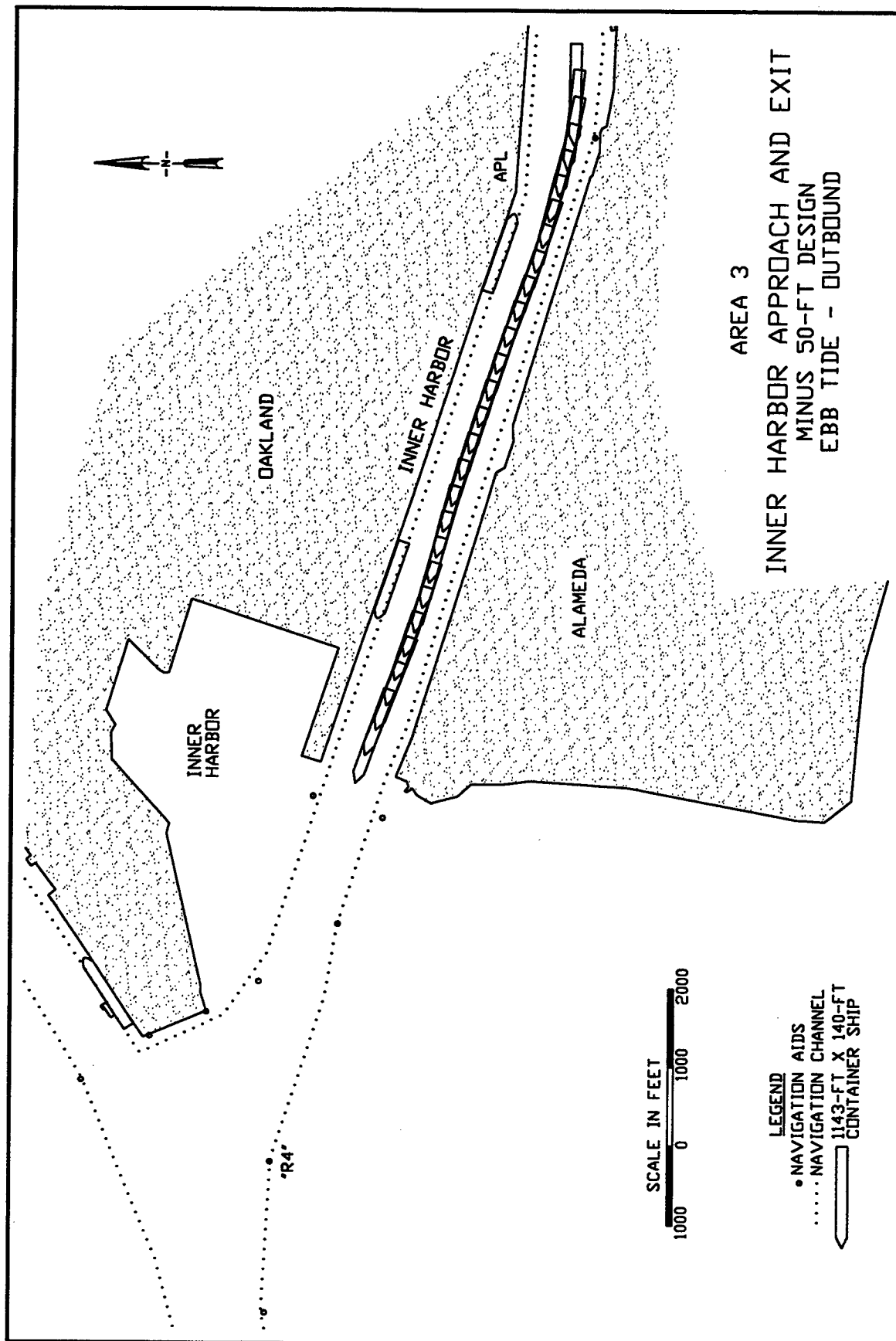


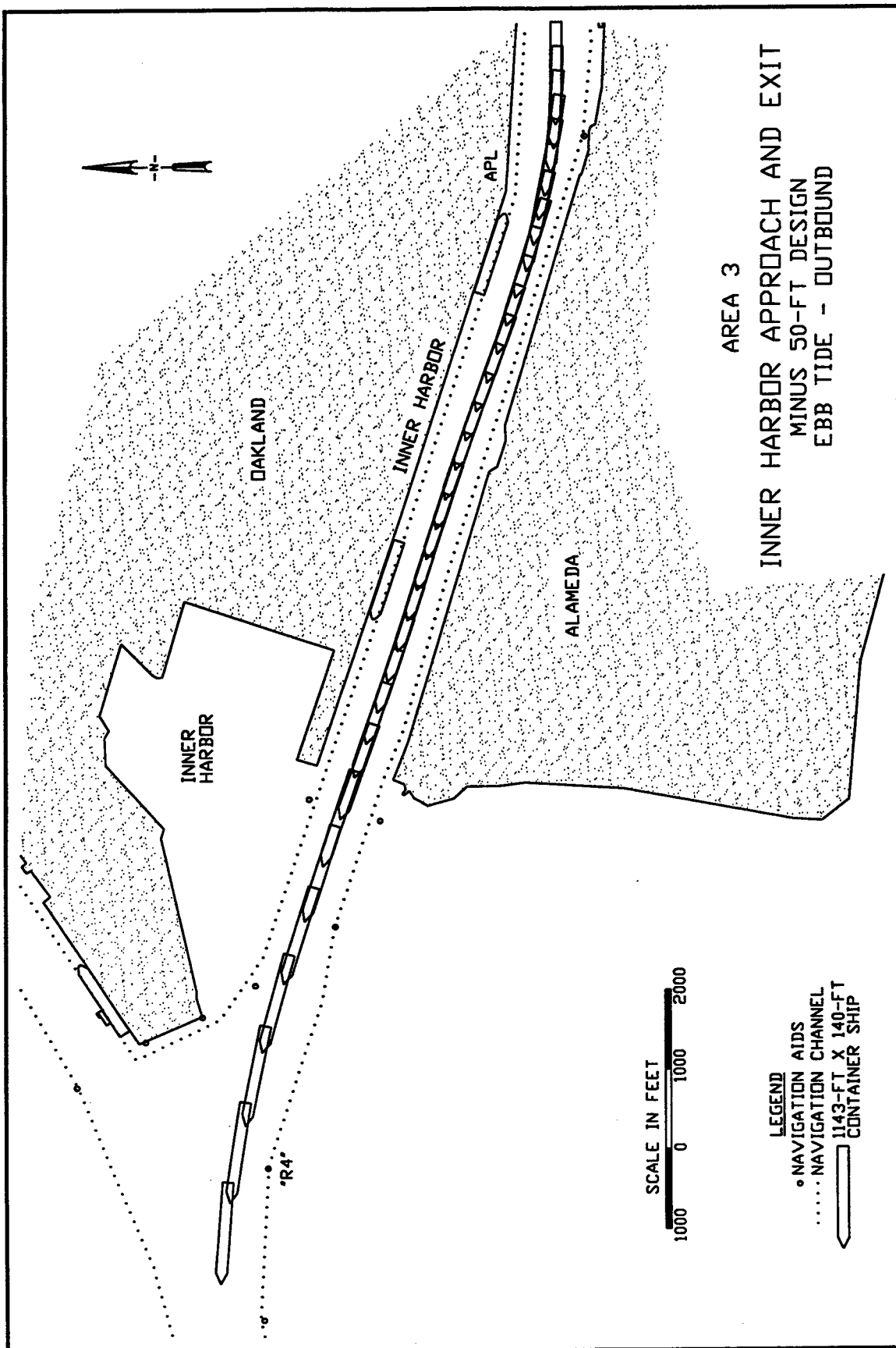


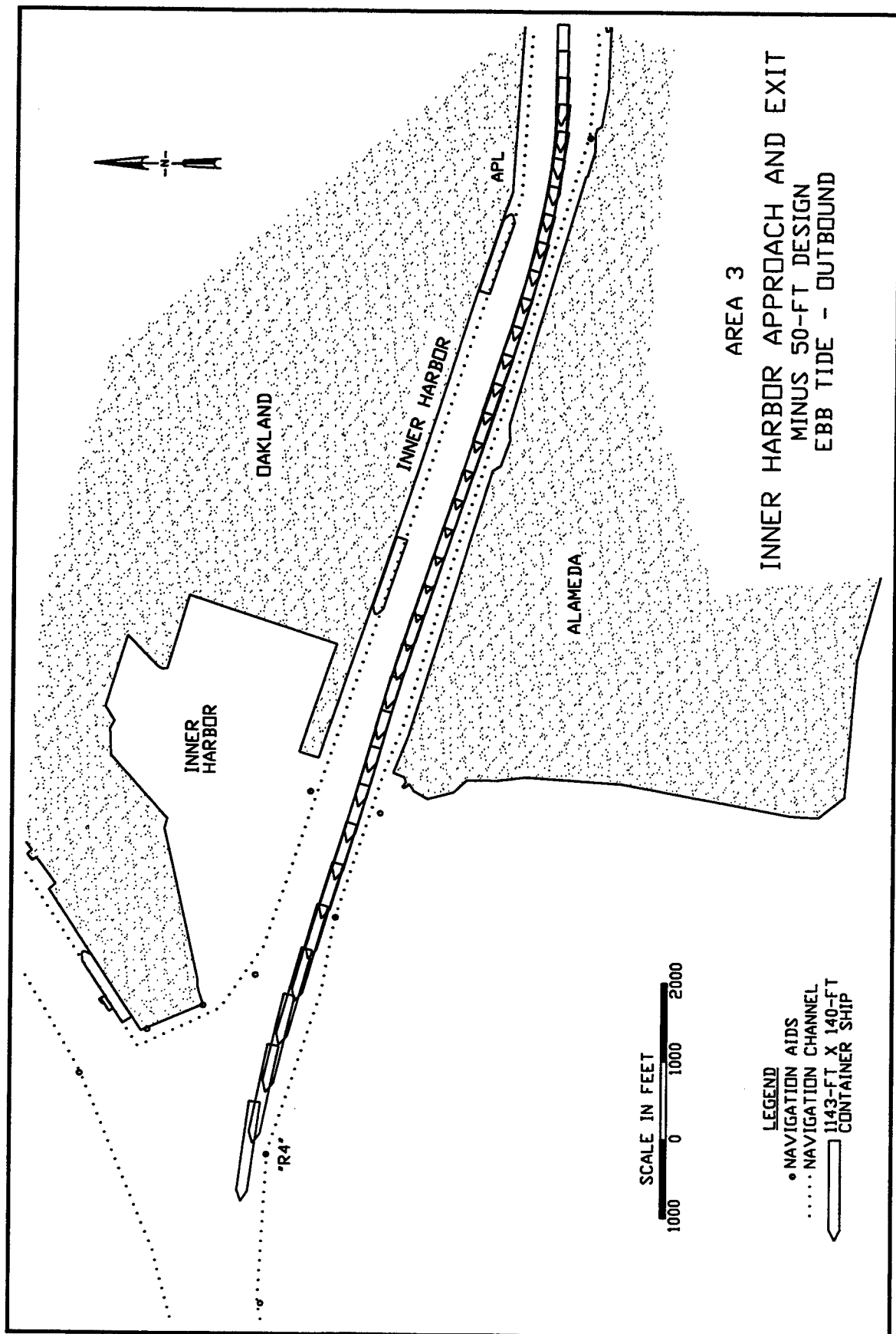


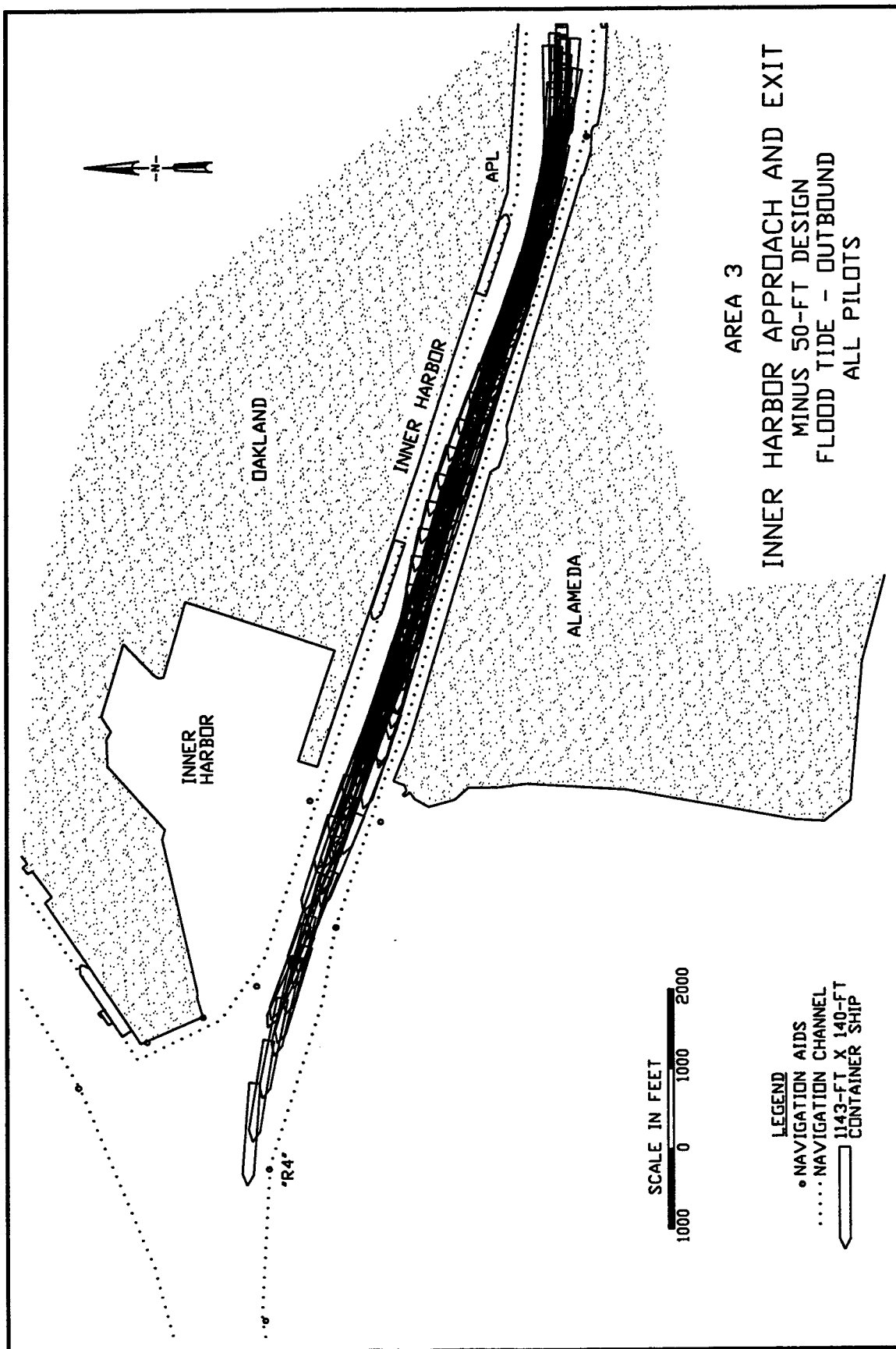


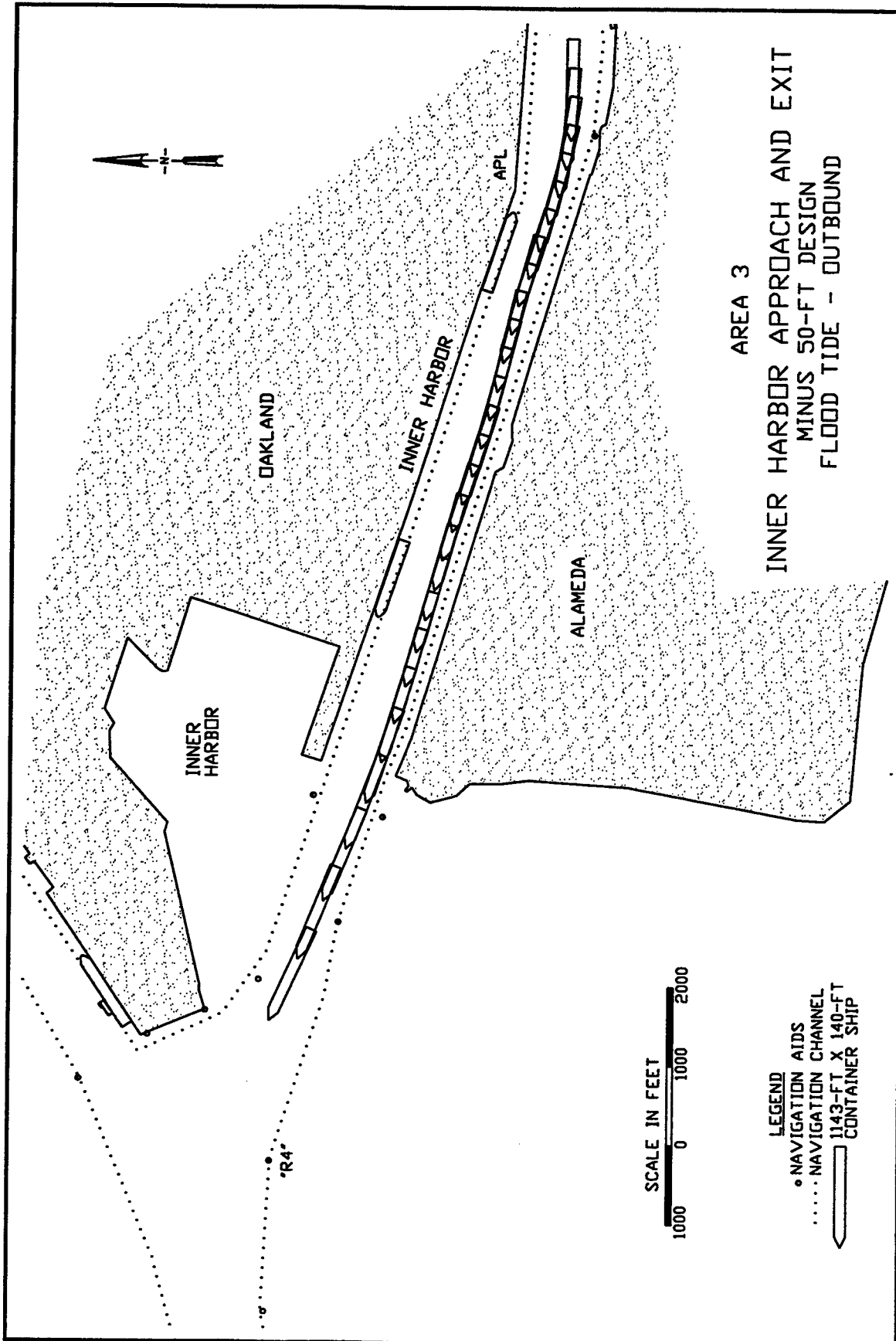


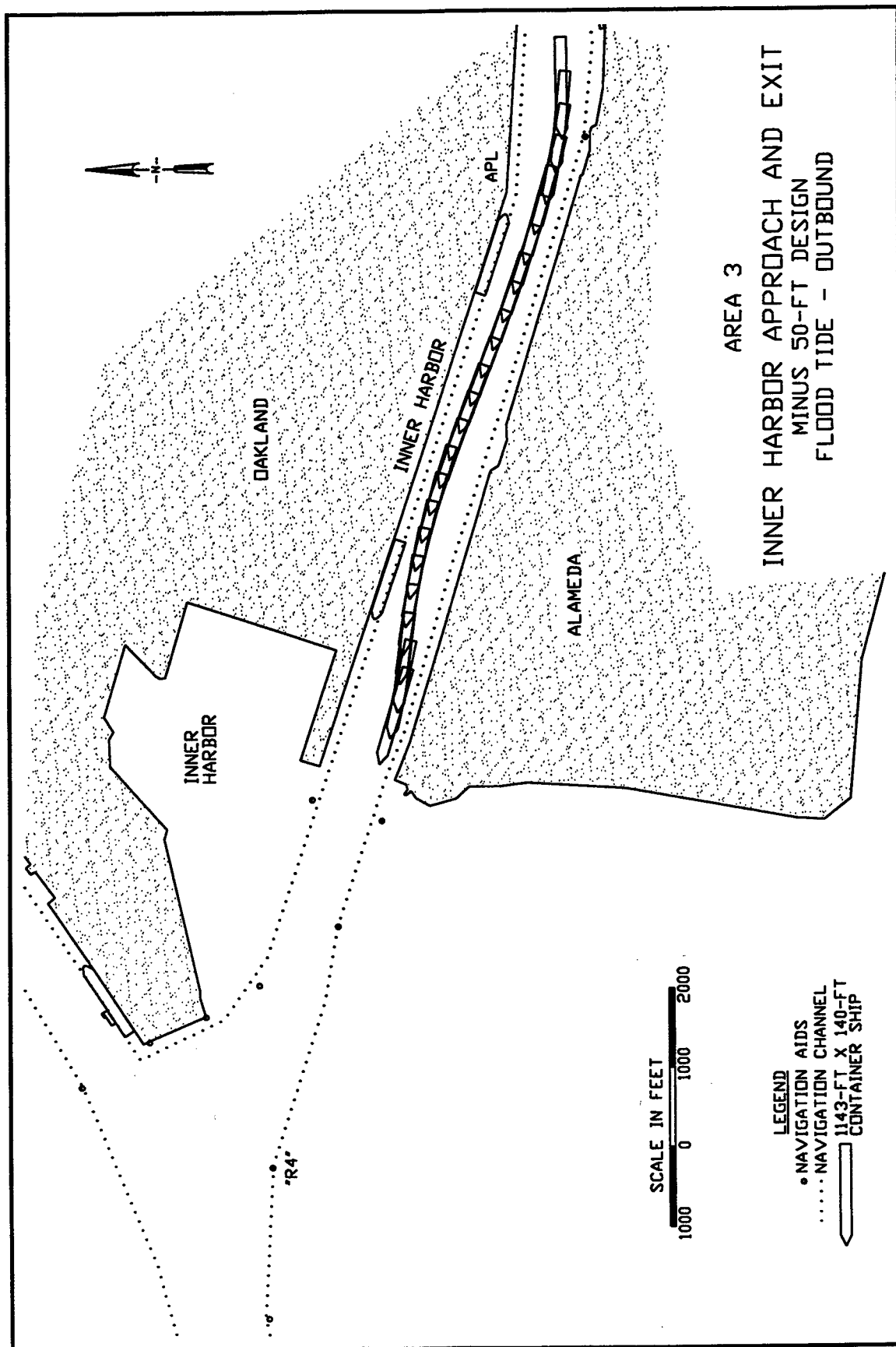


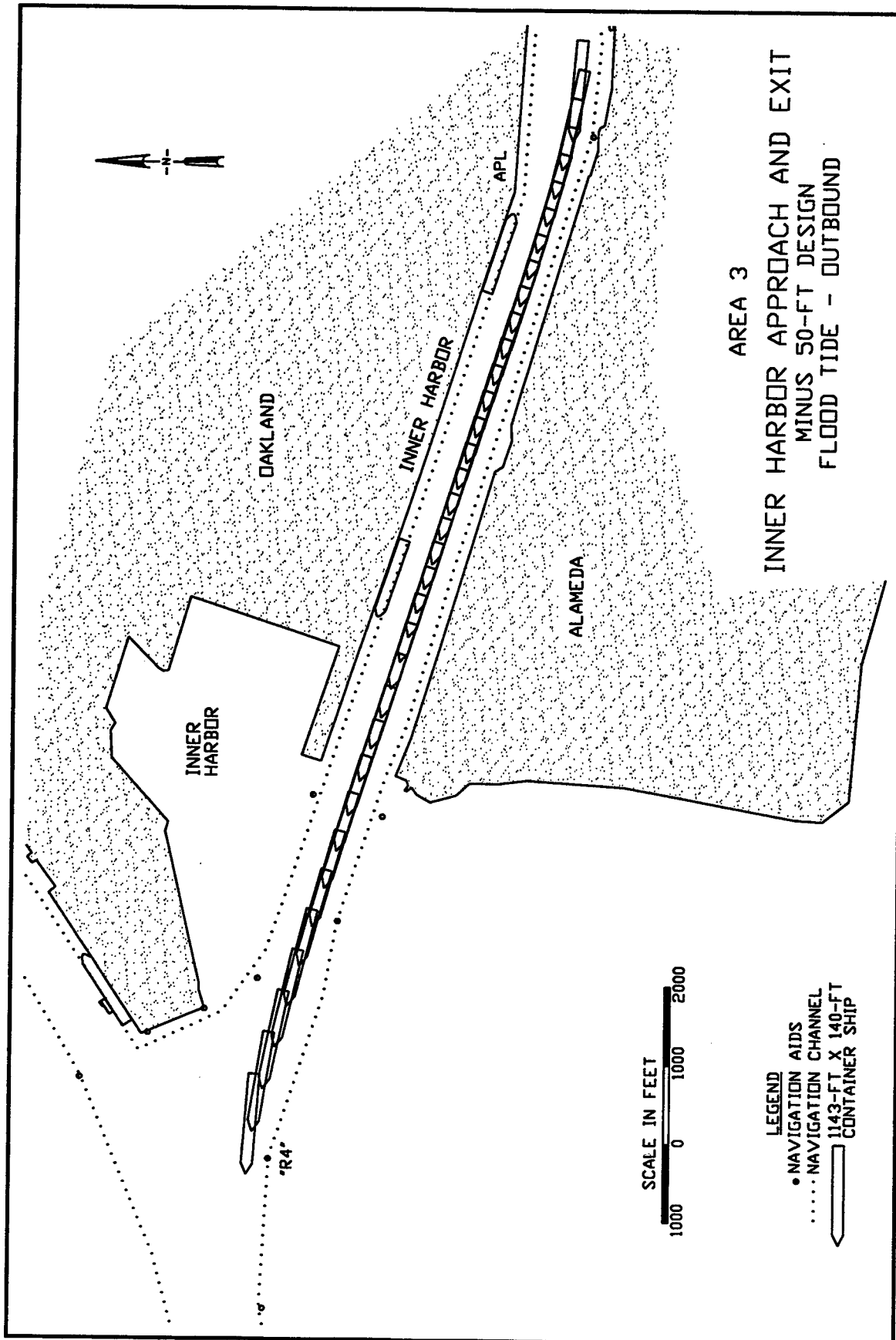


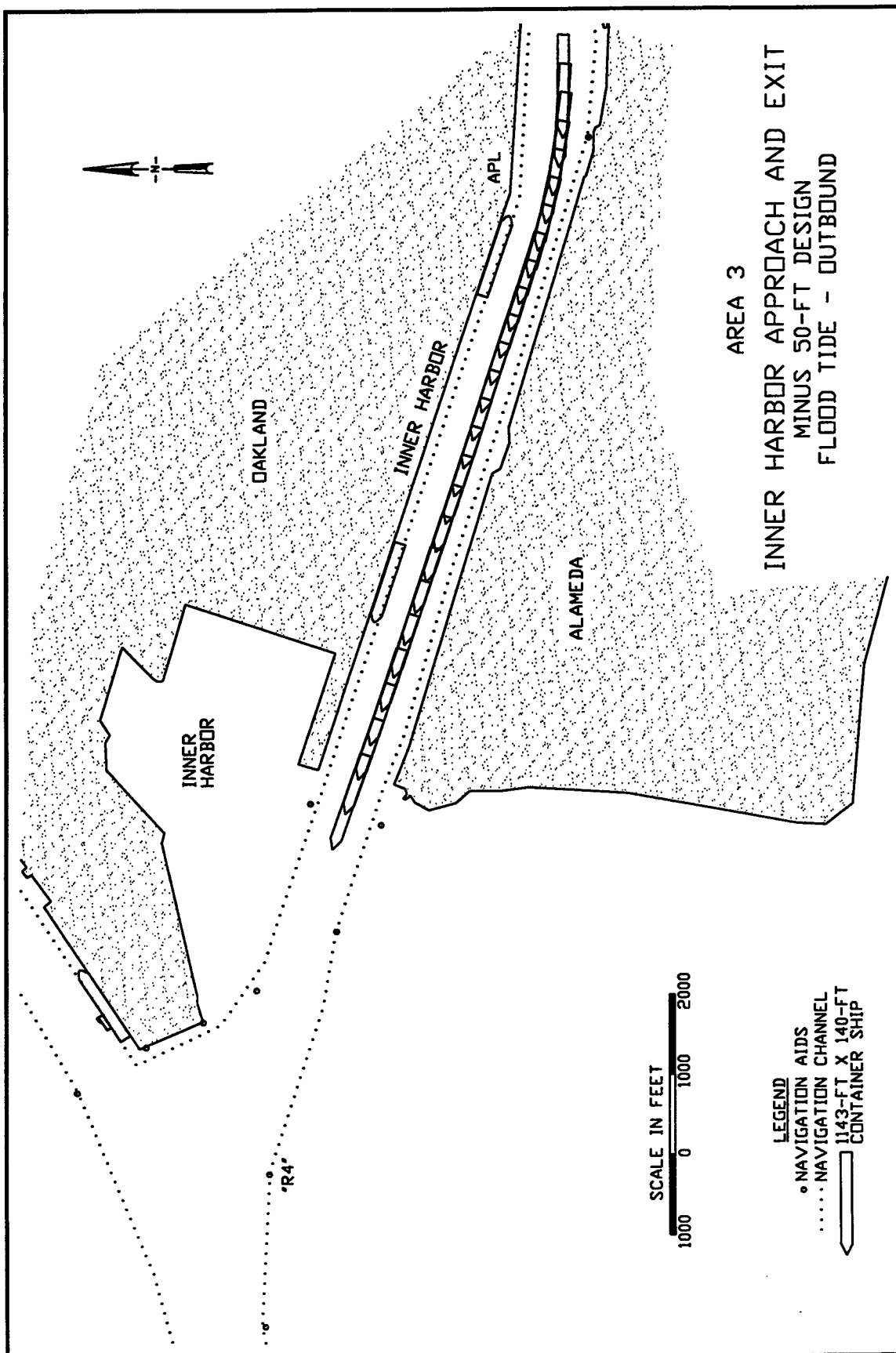


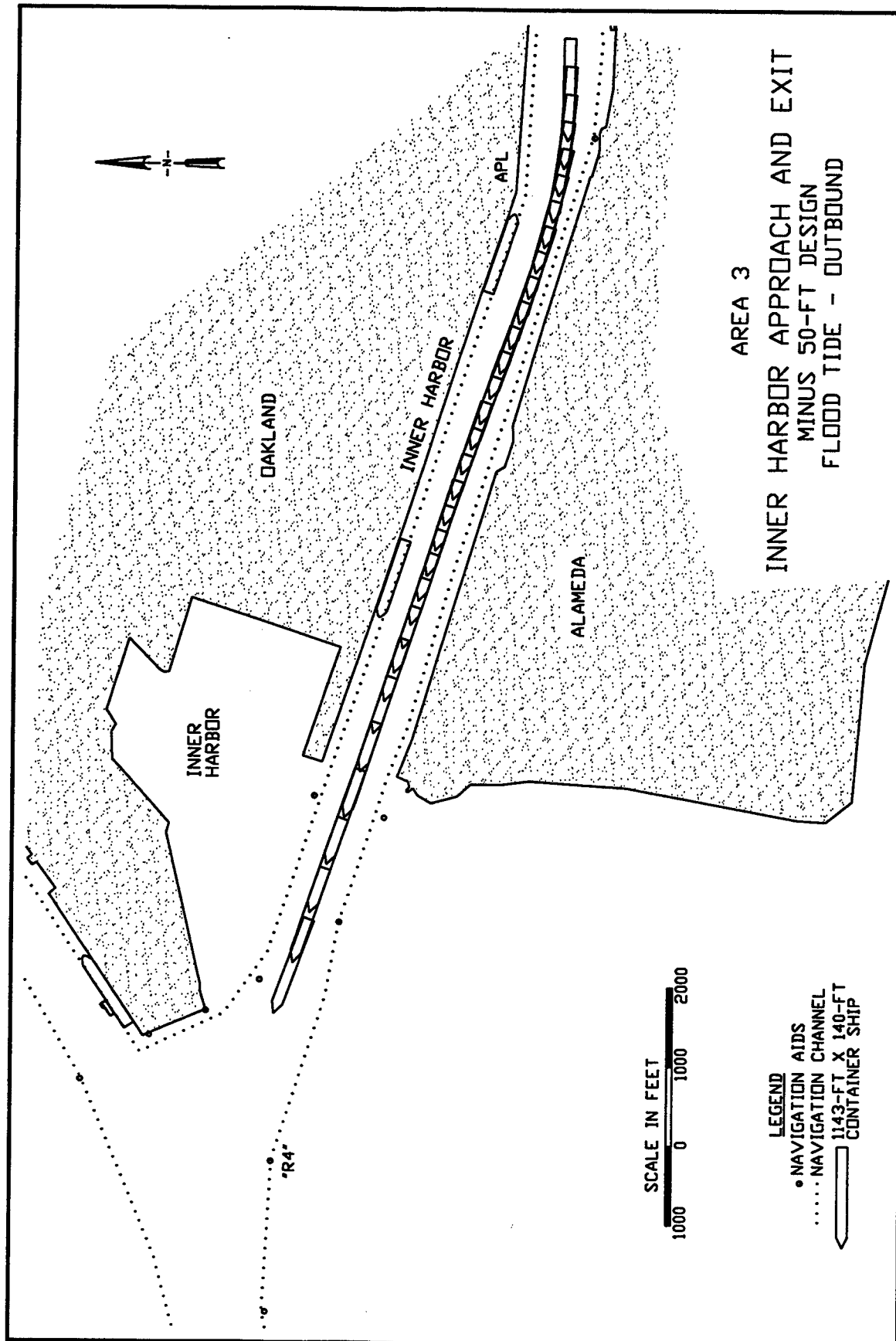




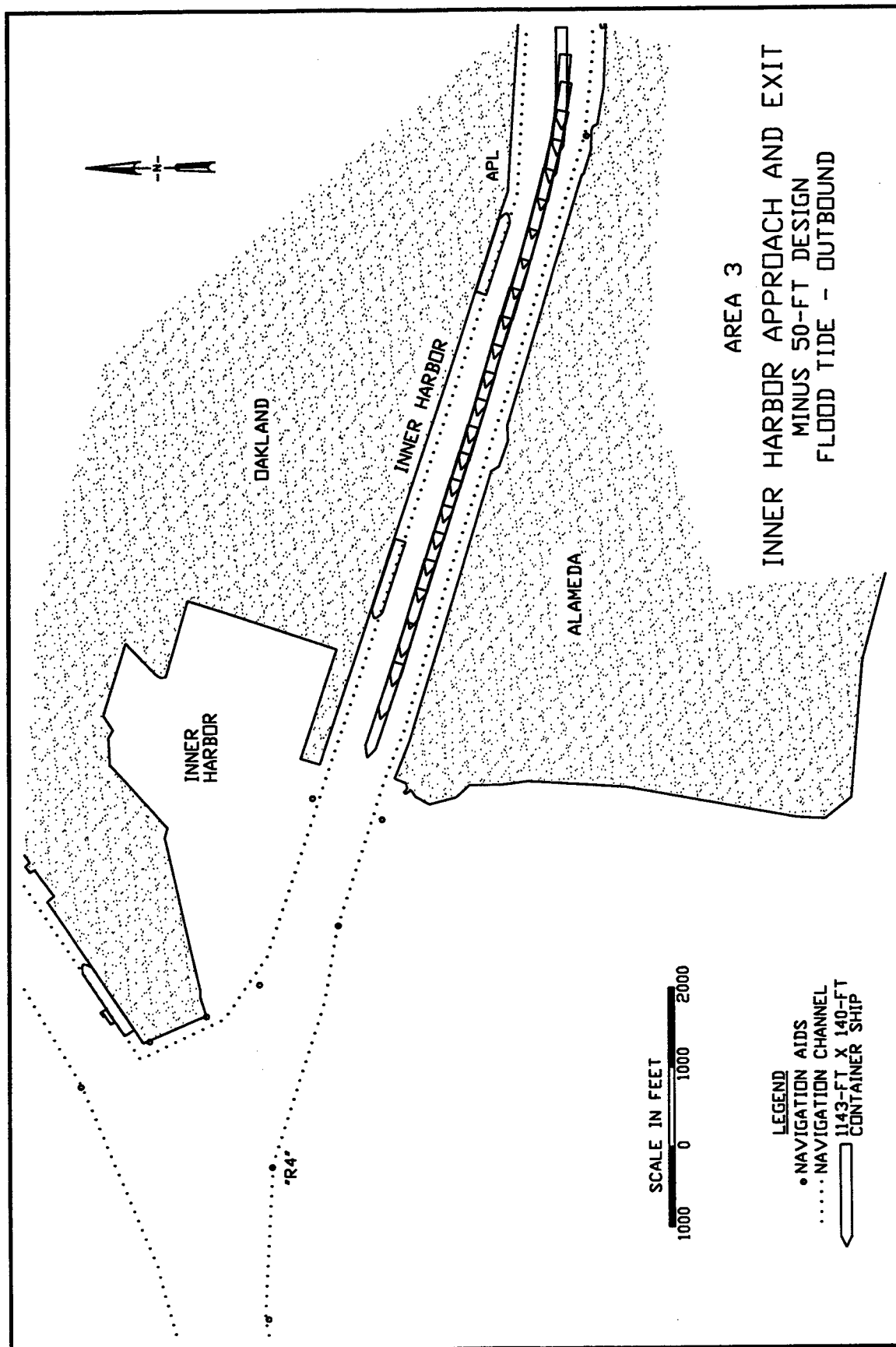


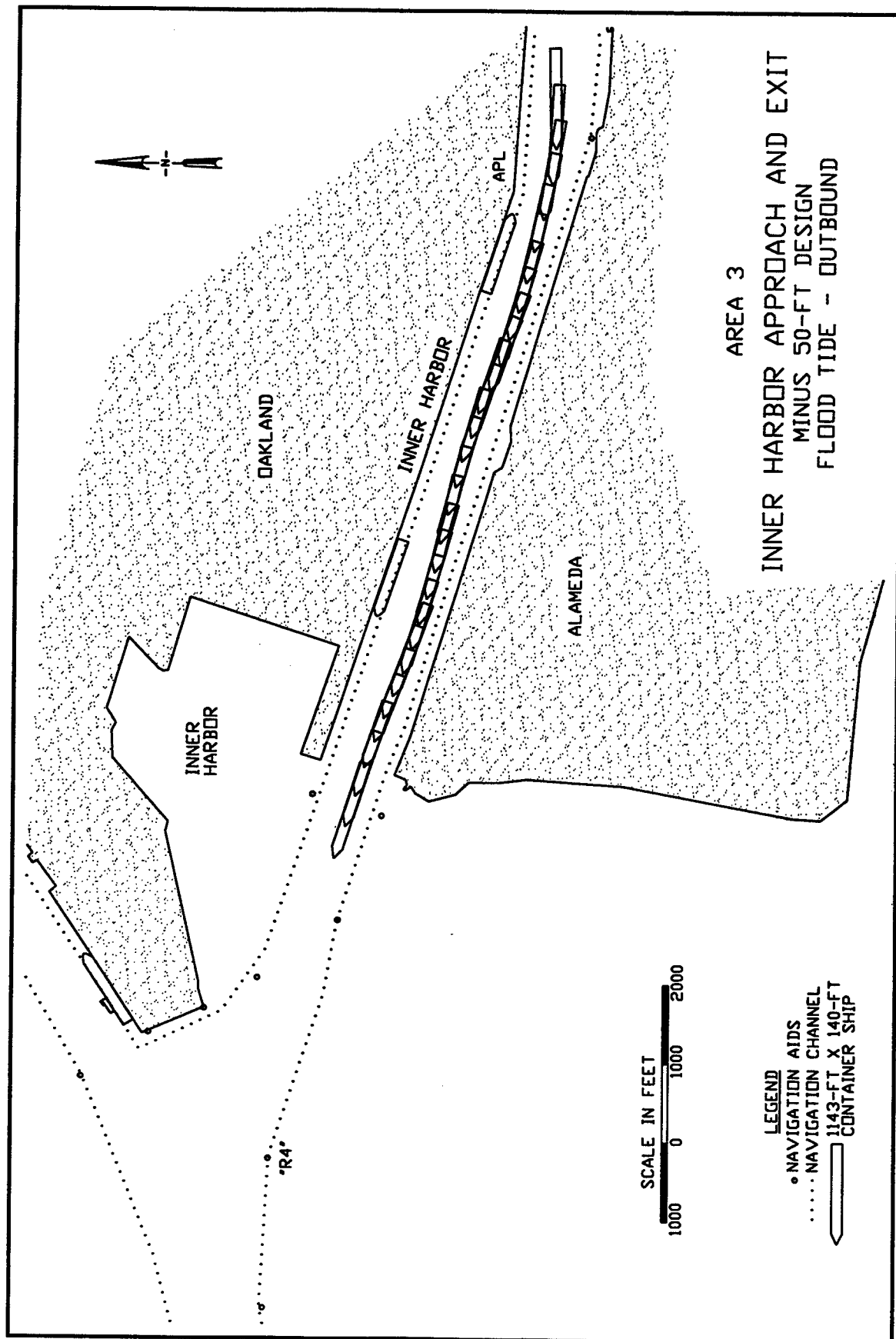


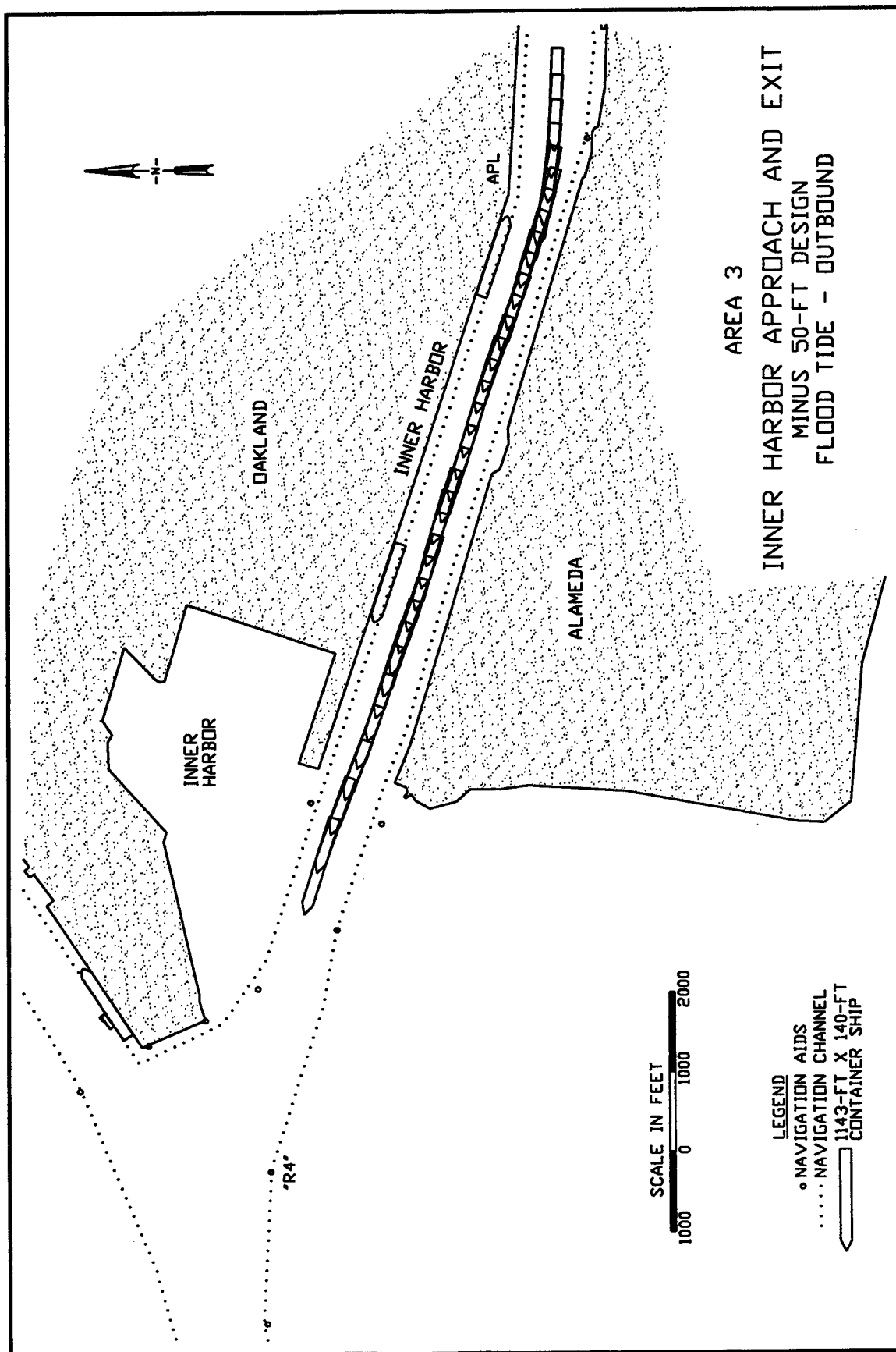


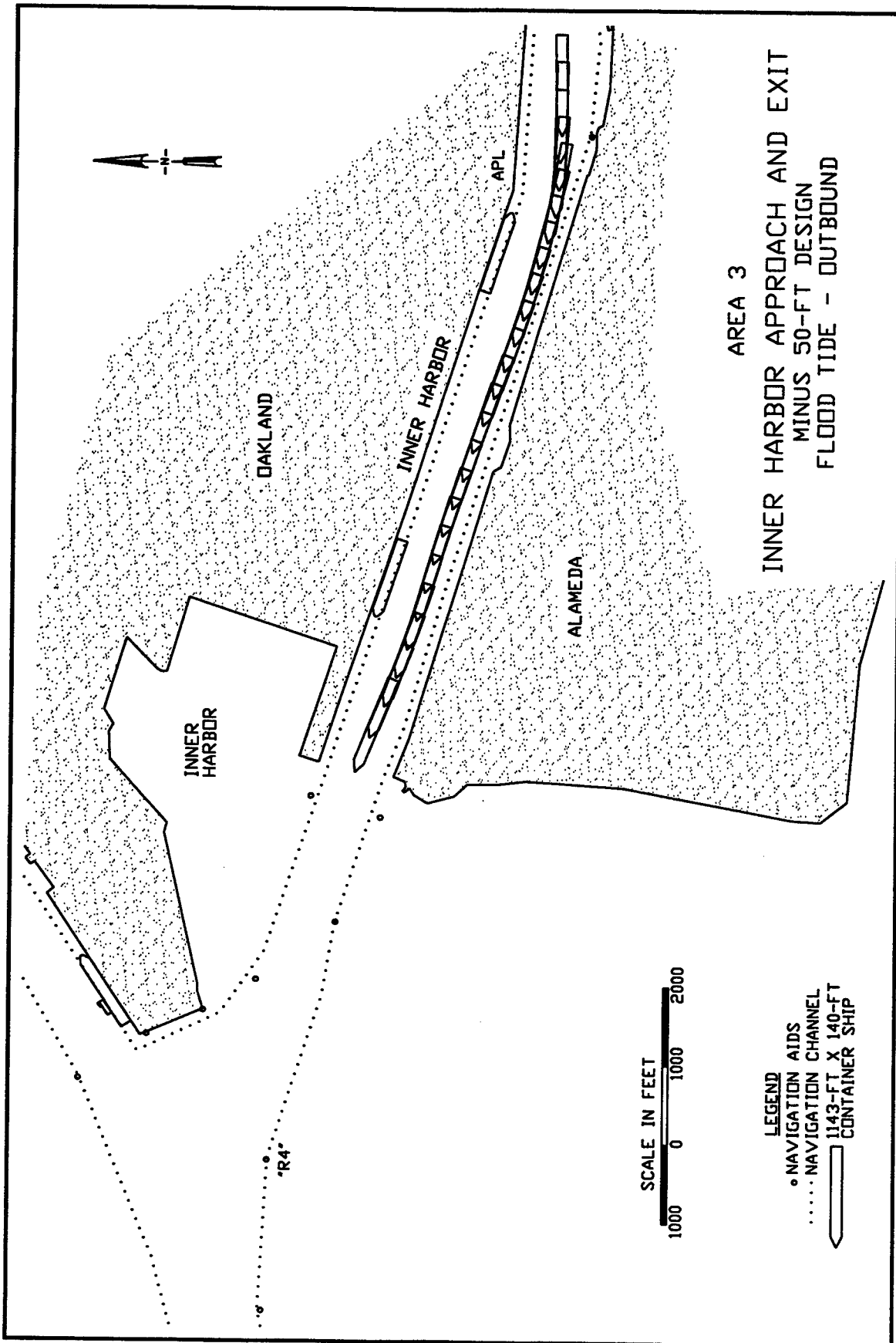


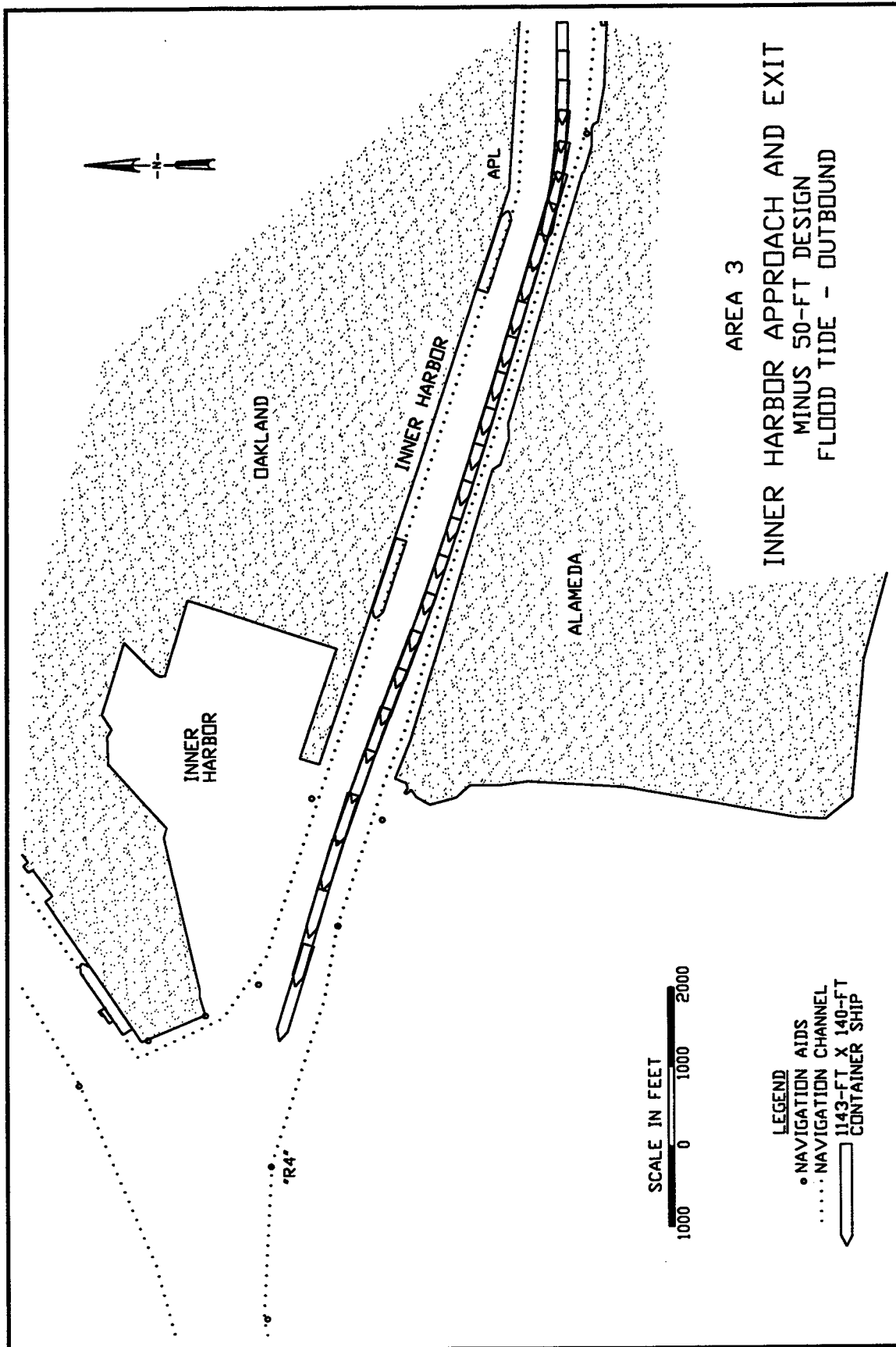
AREA 3
INNER HARBOR APPROACH AND EXIT
MINUS 50-FT DESIGN
FLOOD TIDE - OUTBOUND

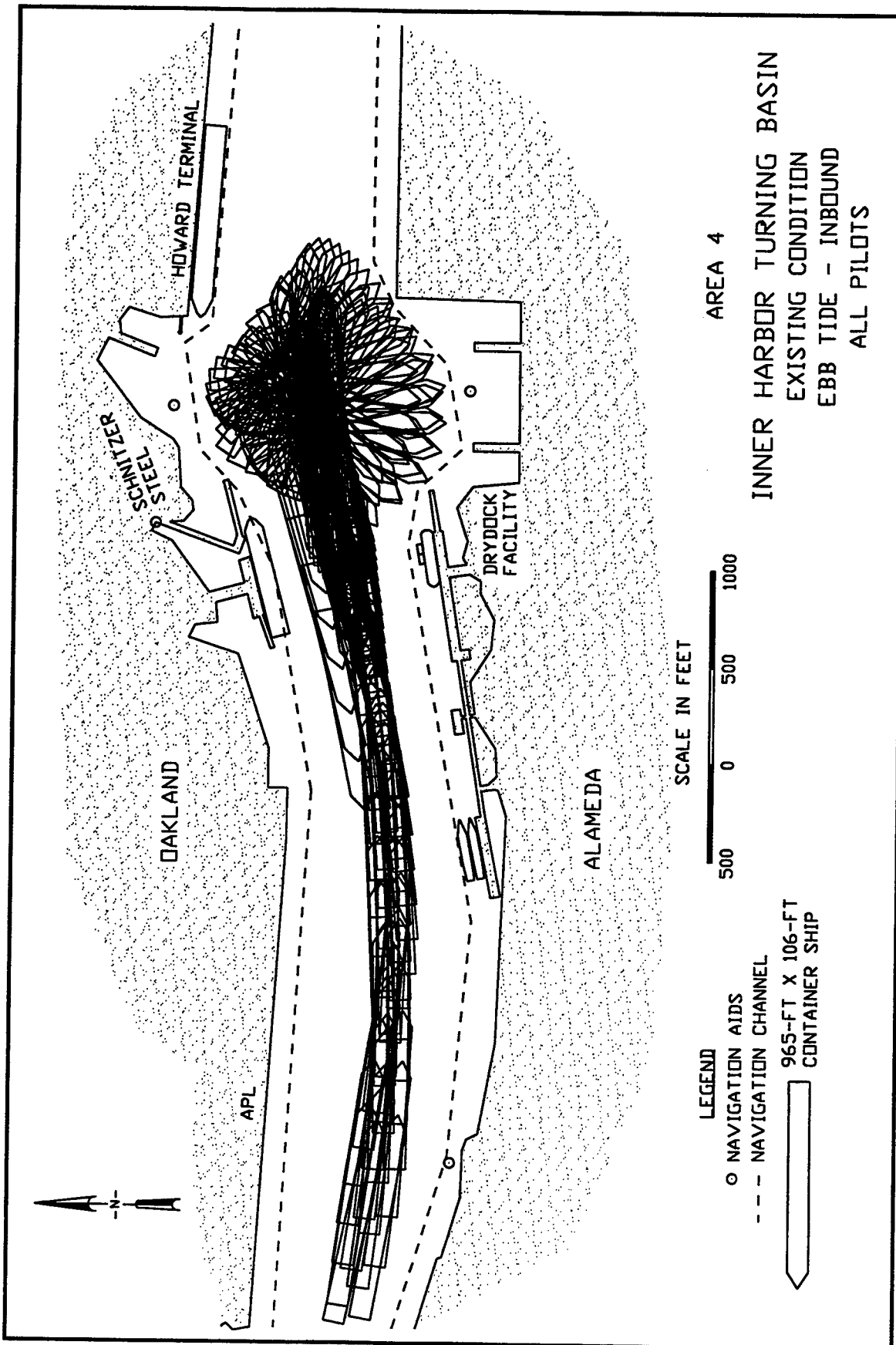


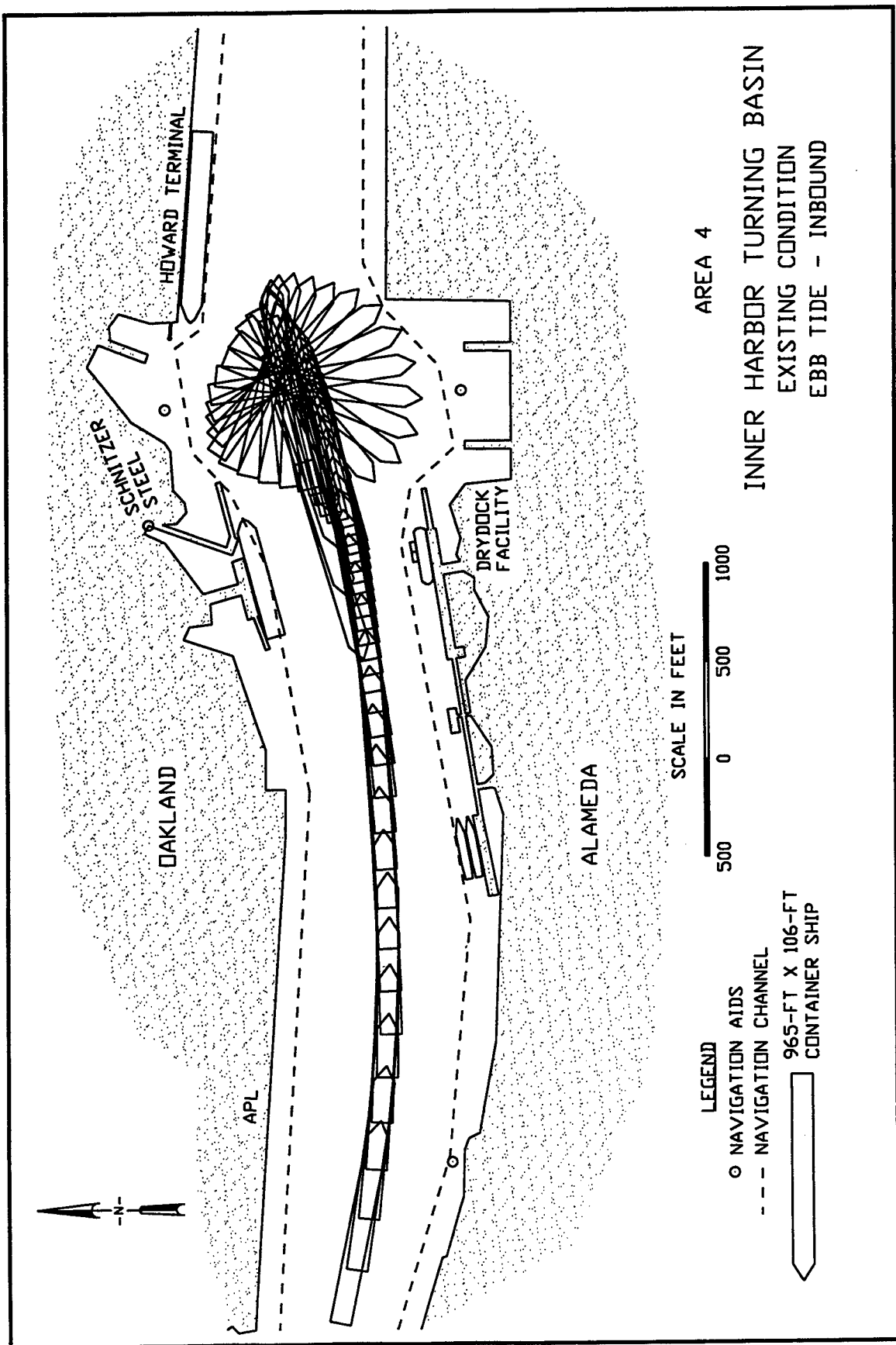


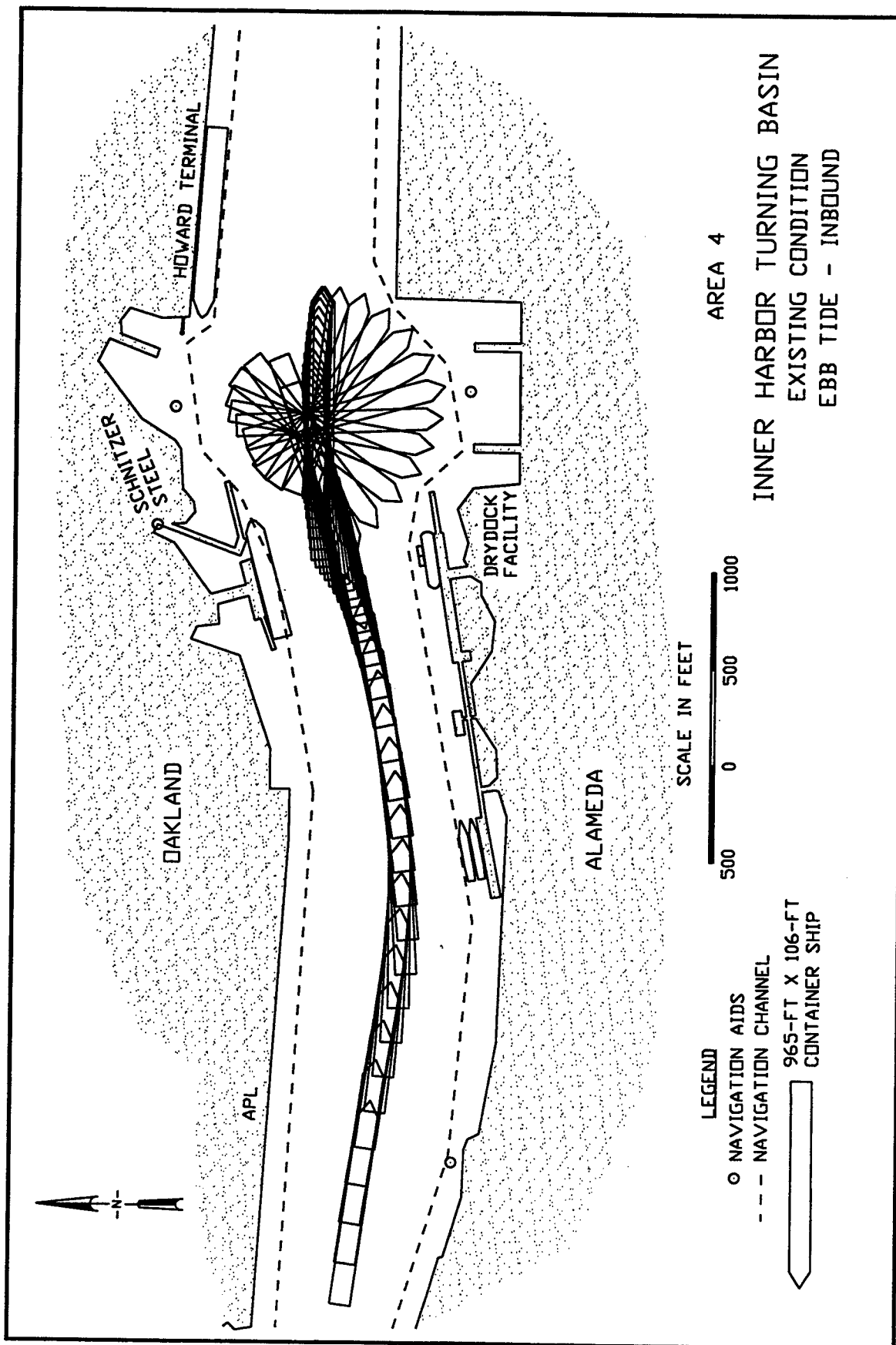


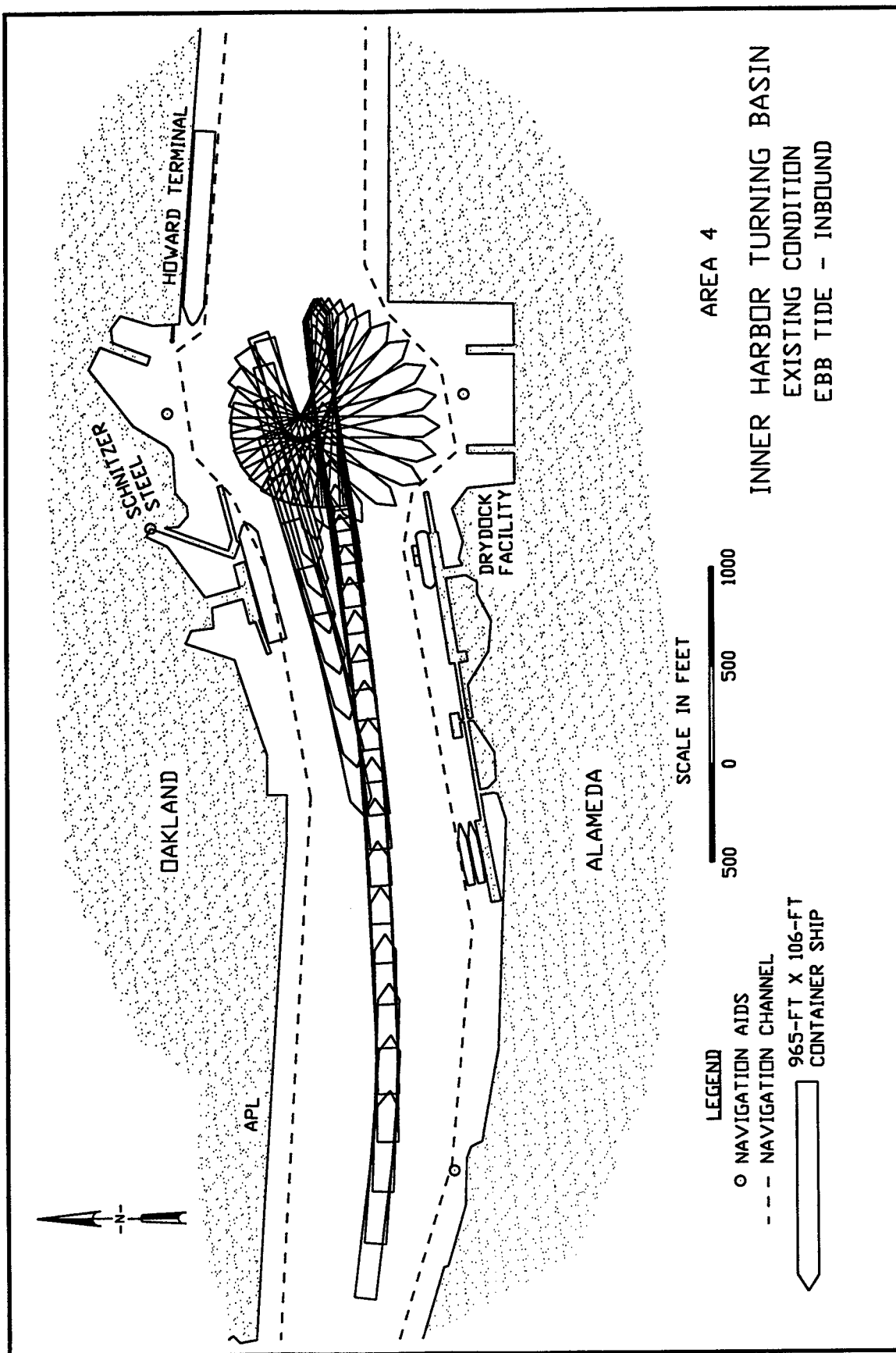


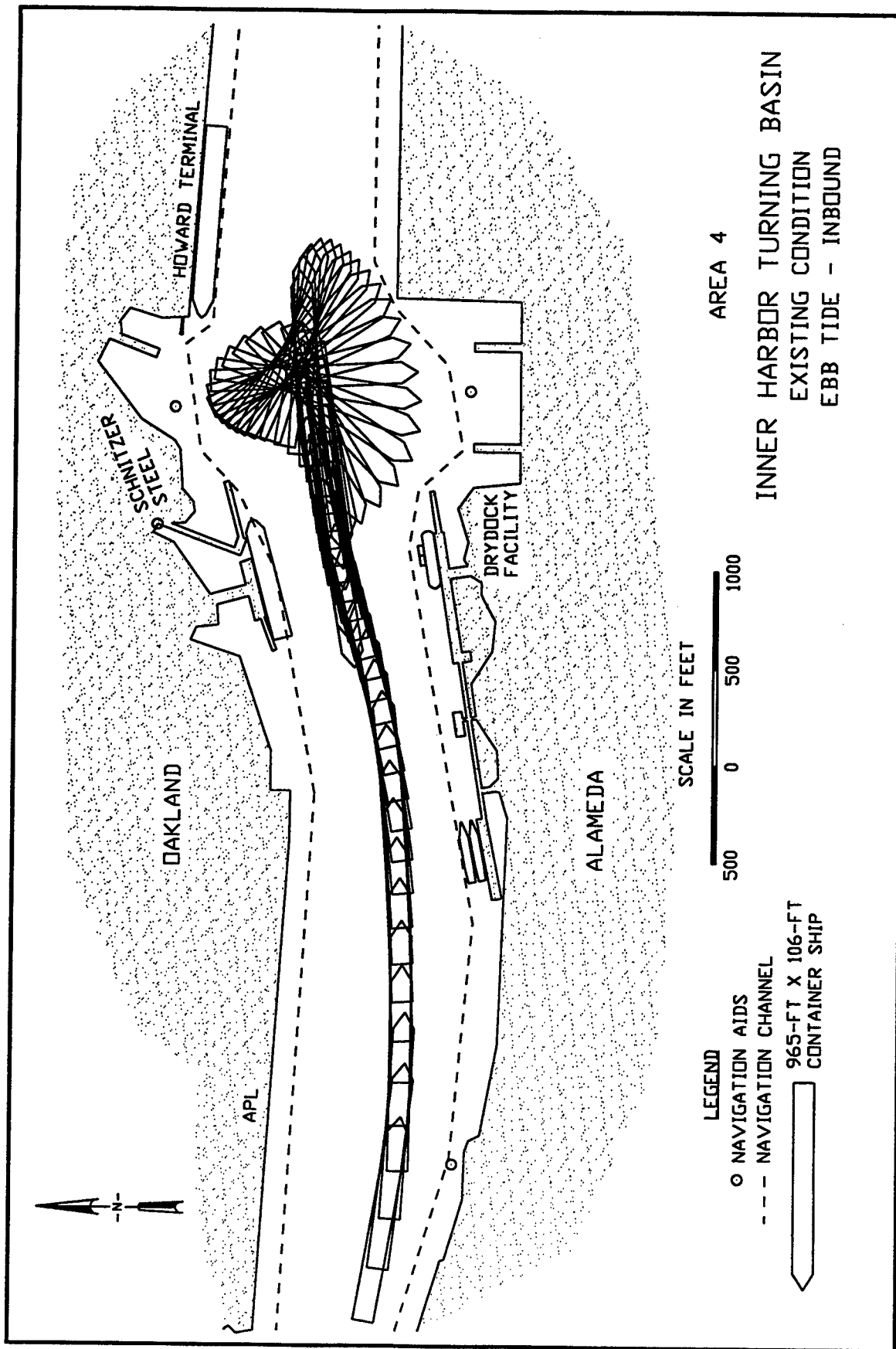


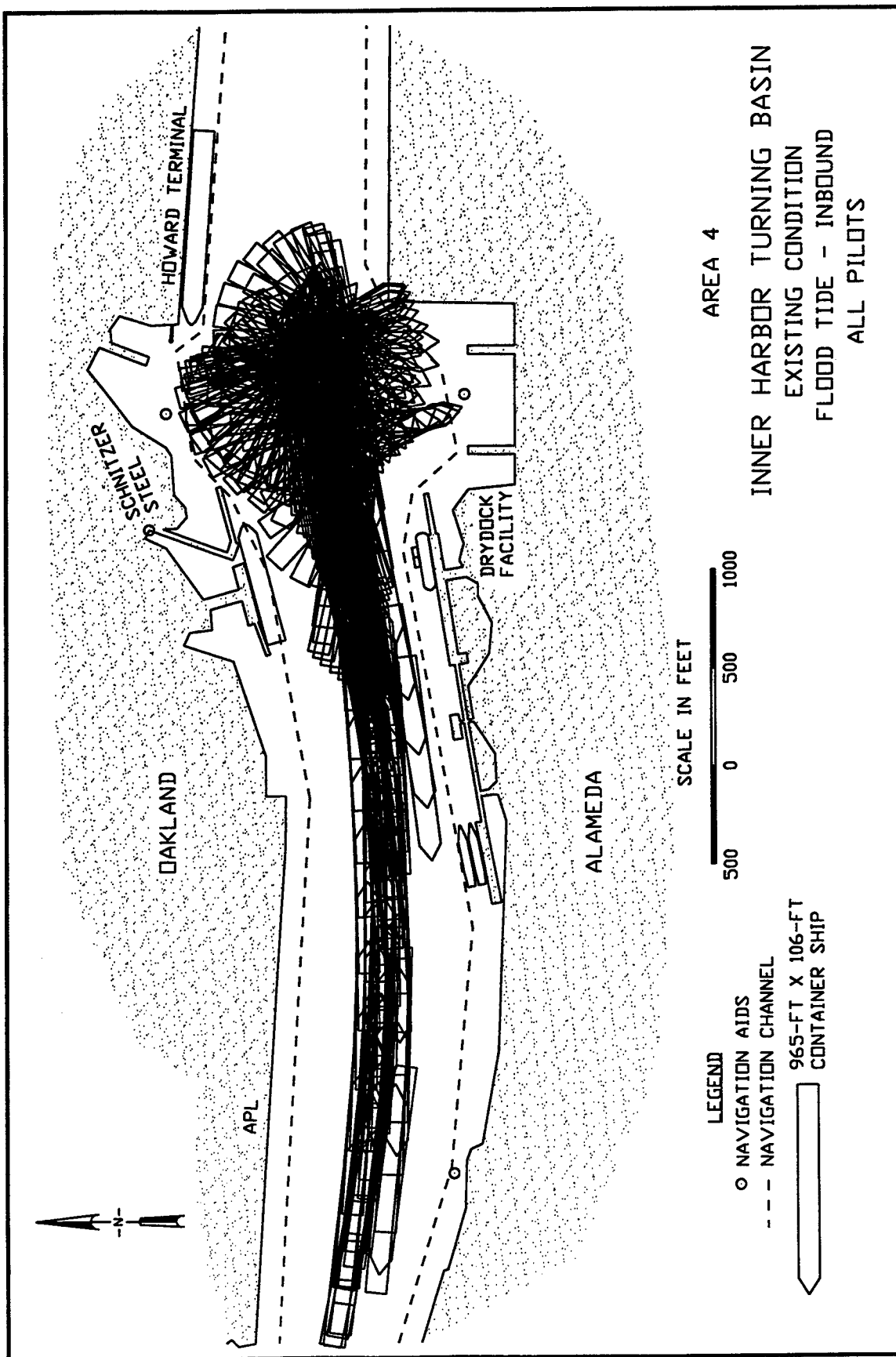


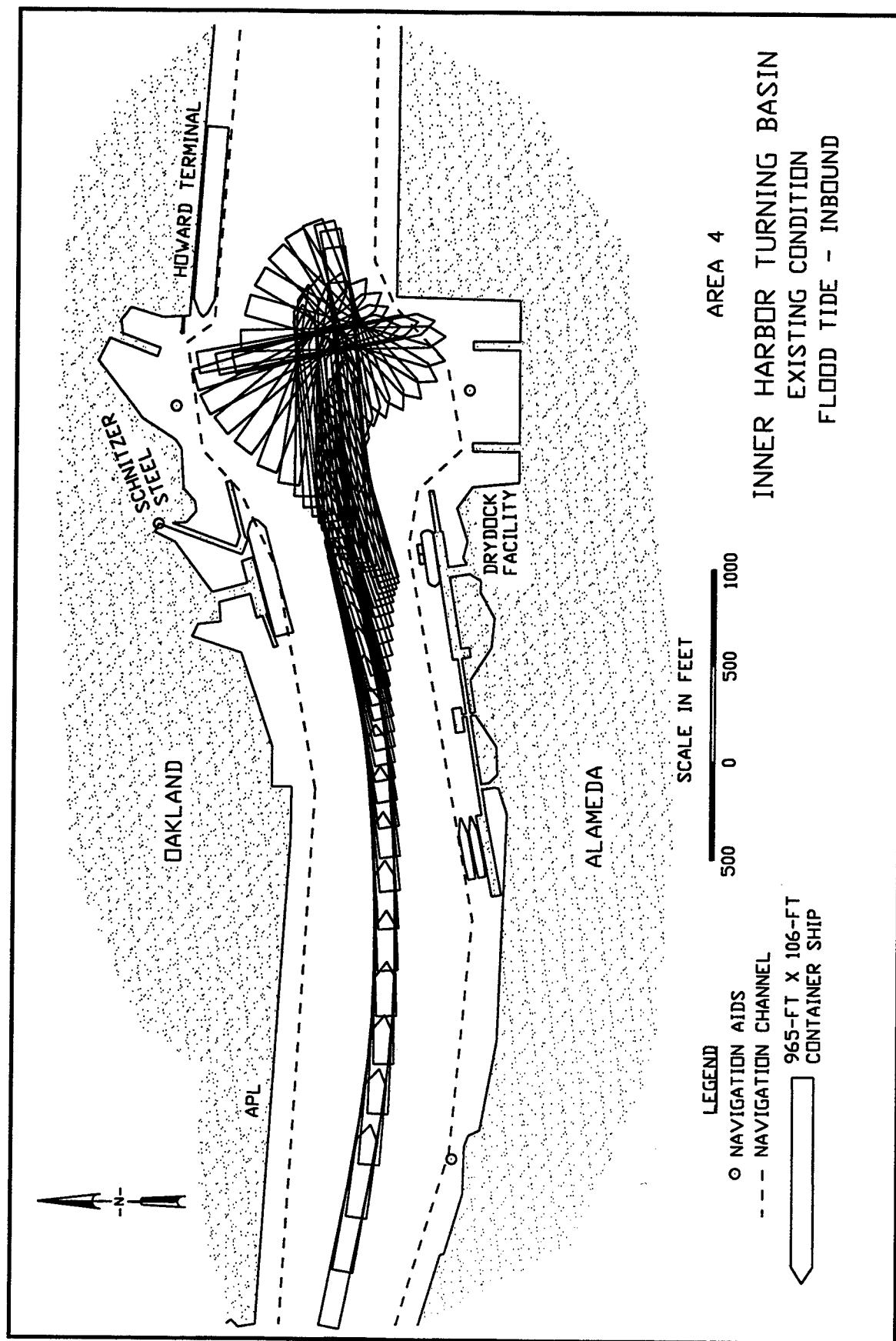


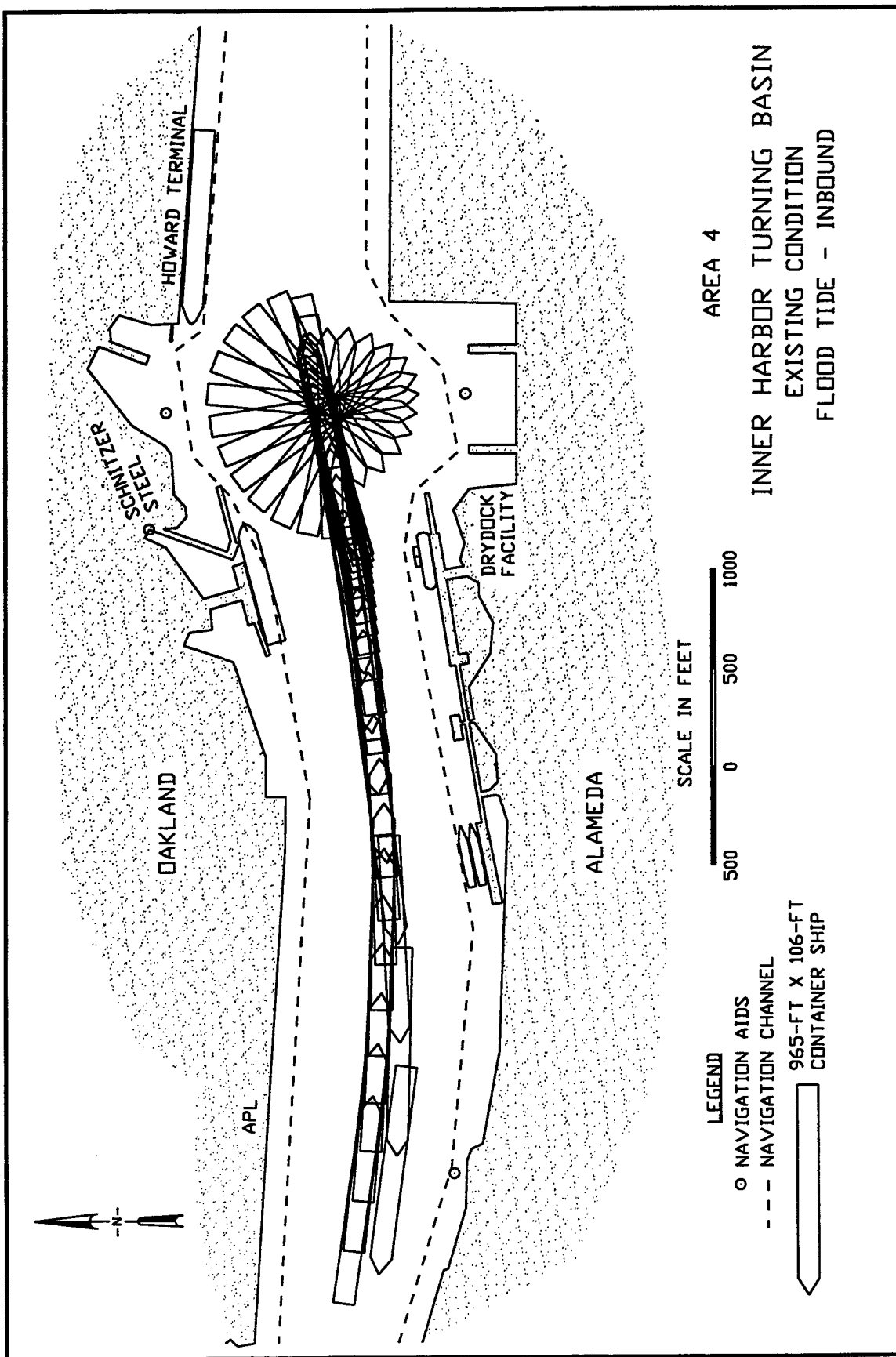


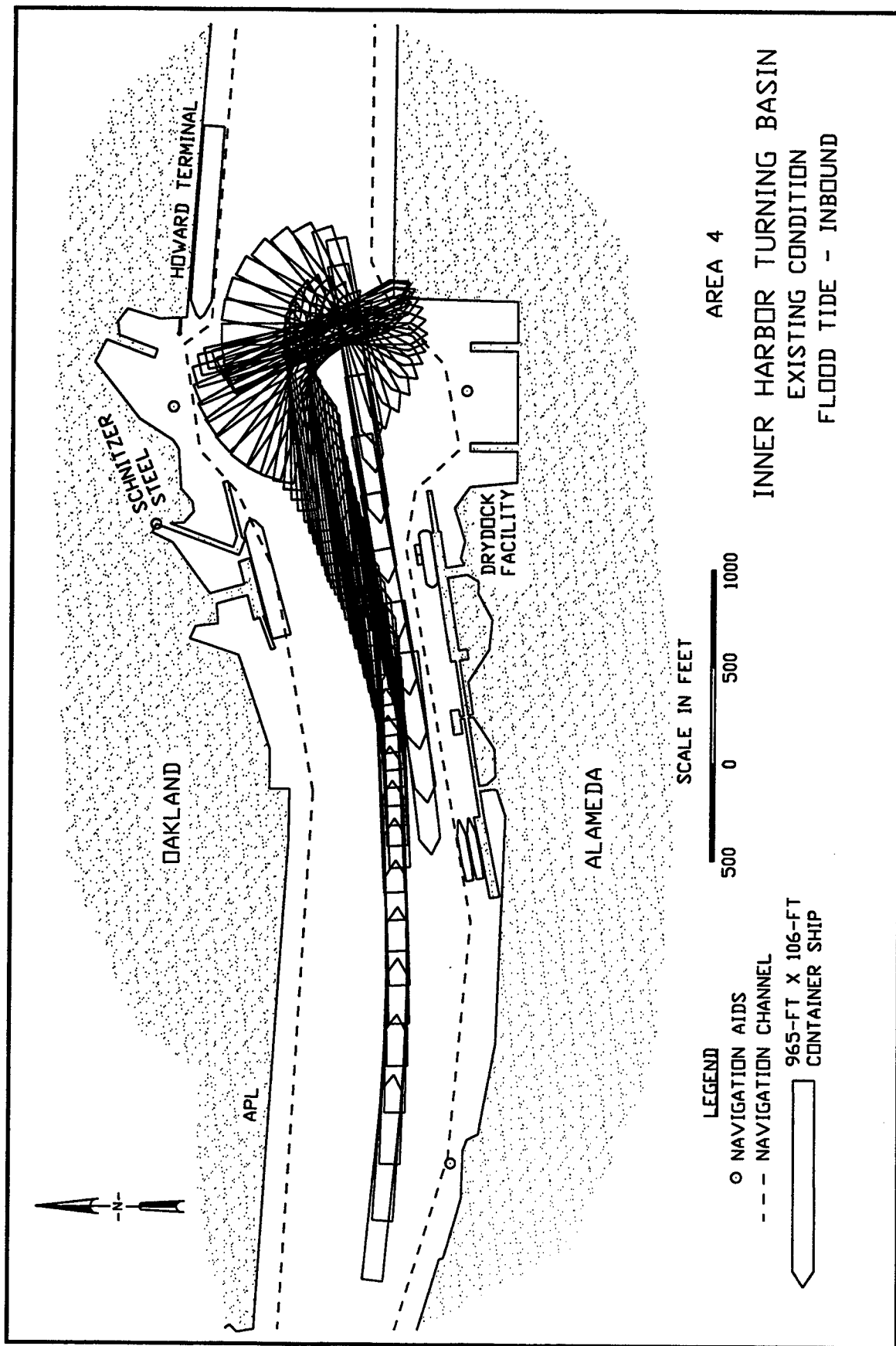


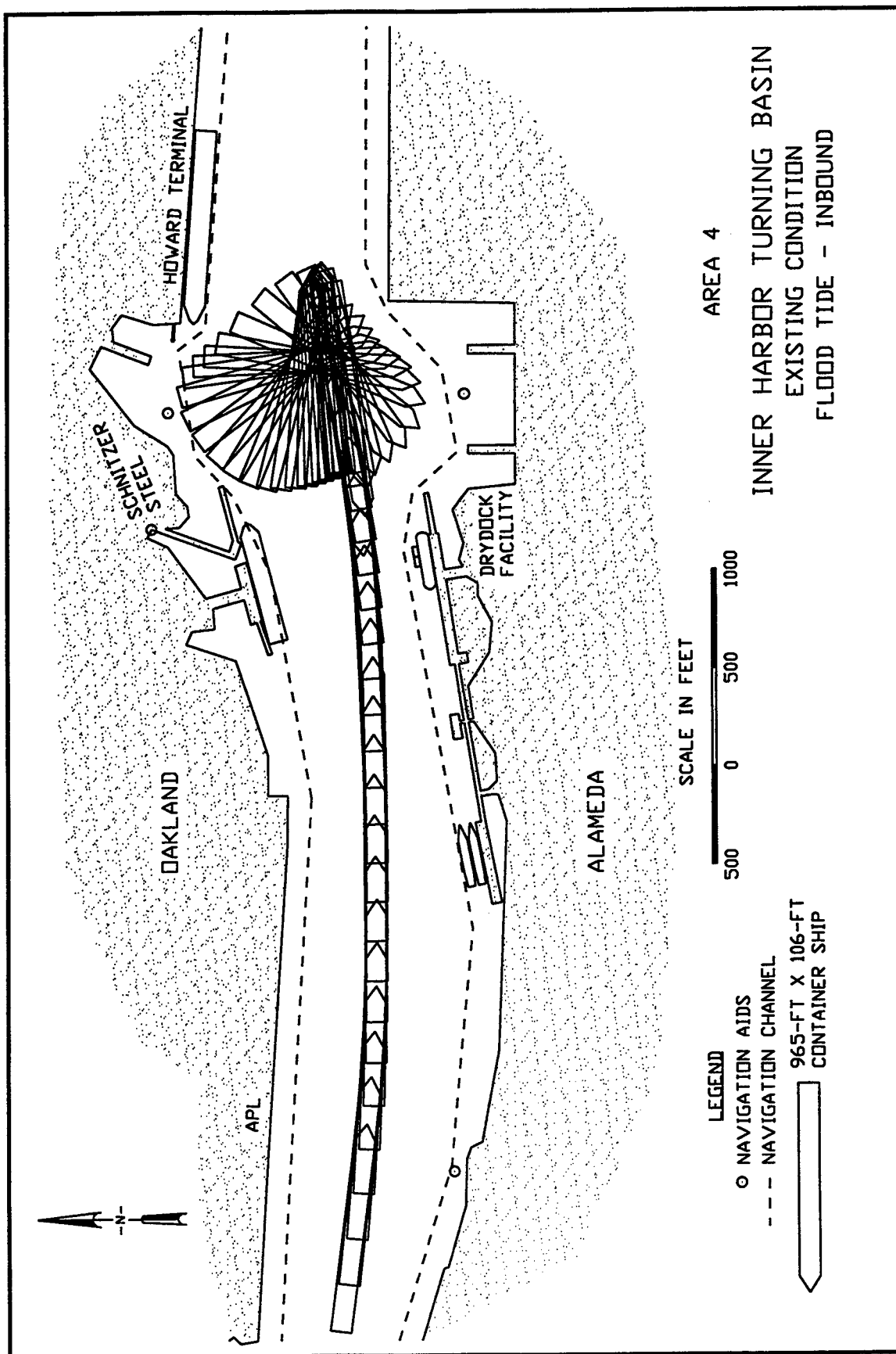


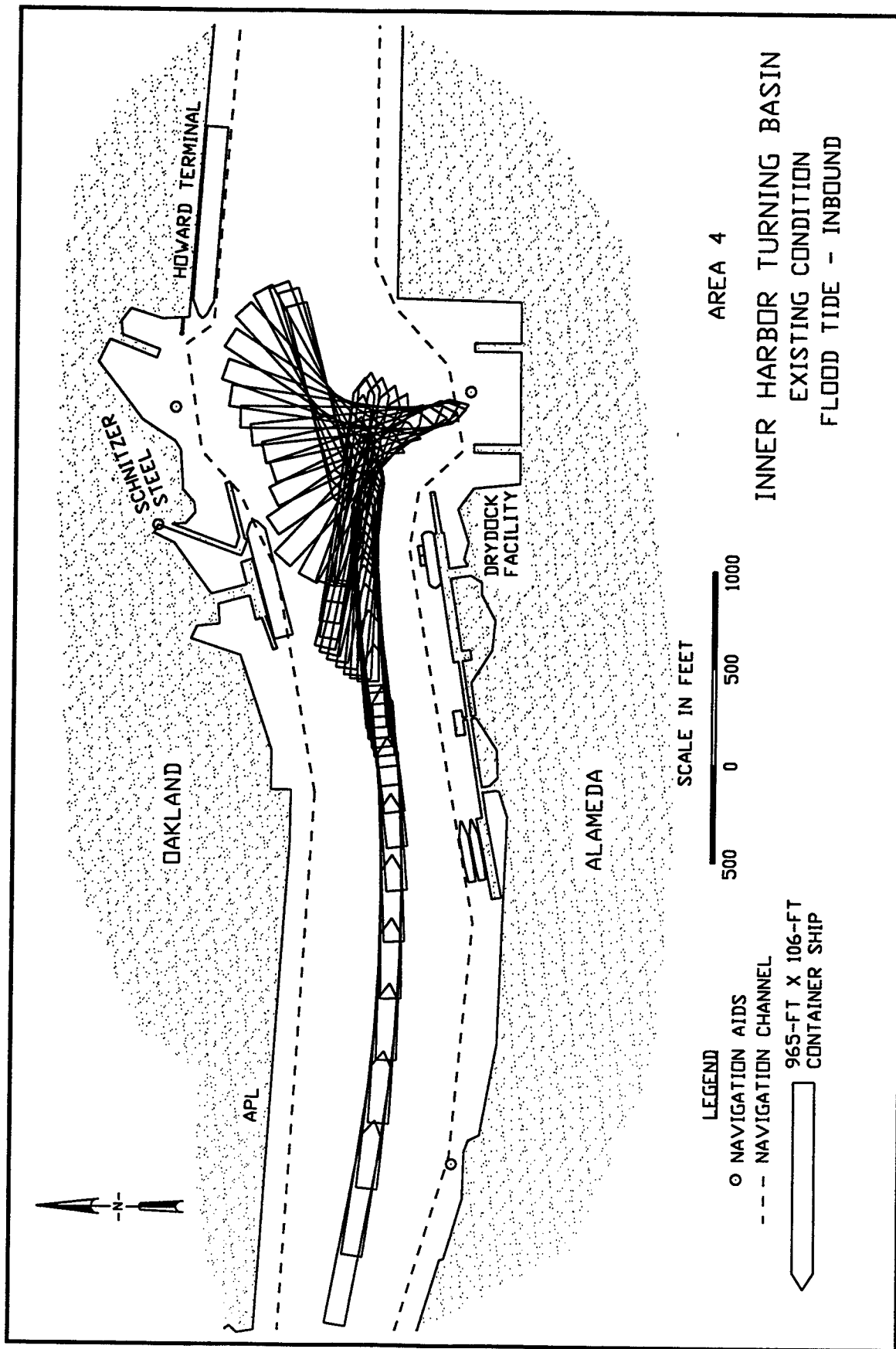


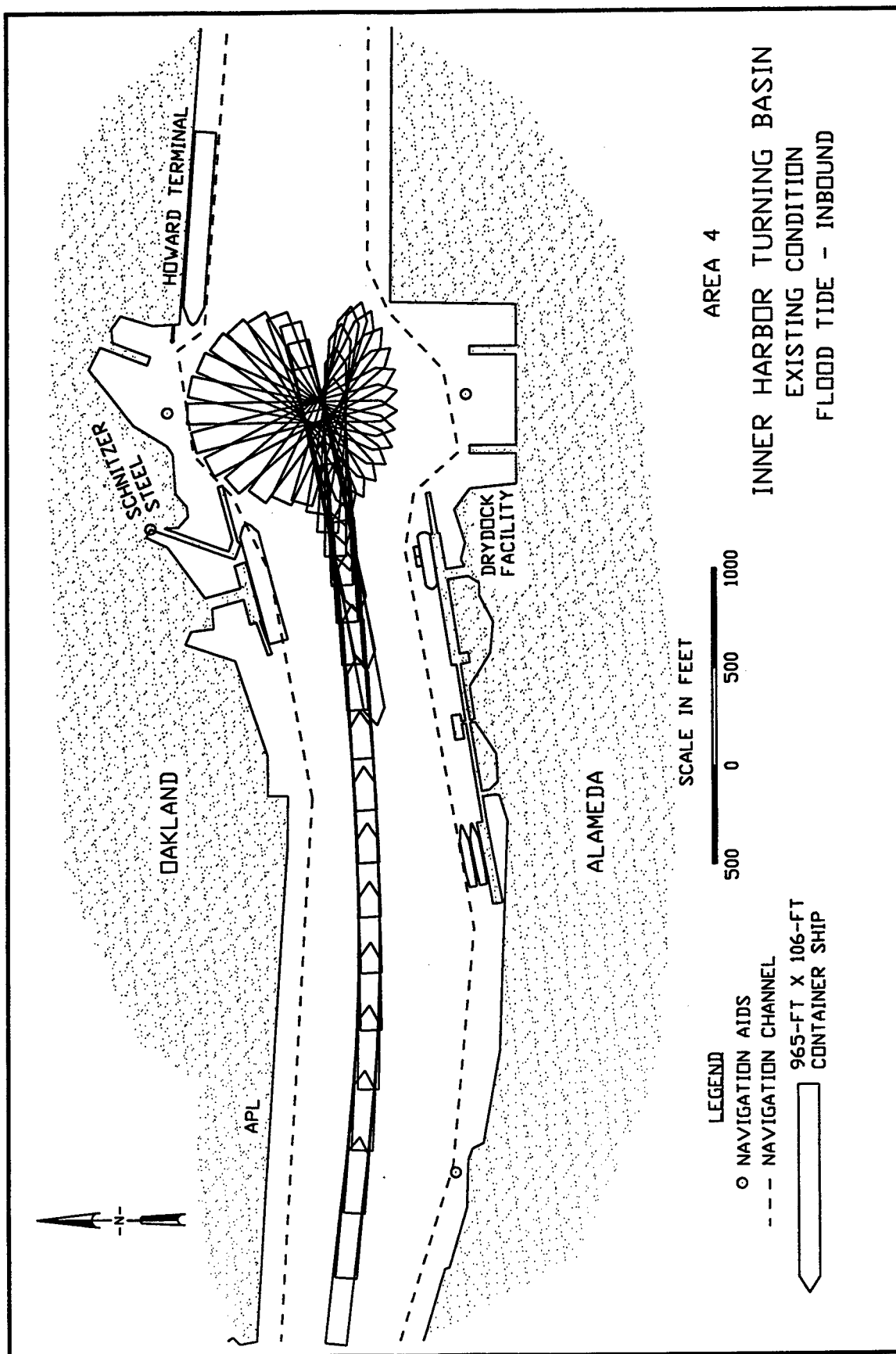


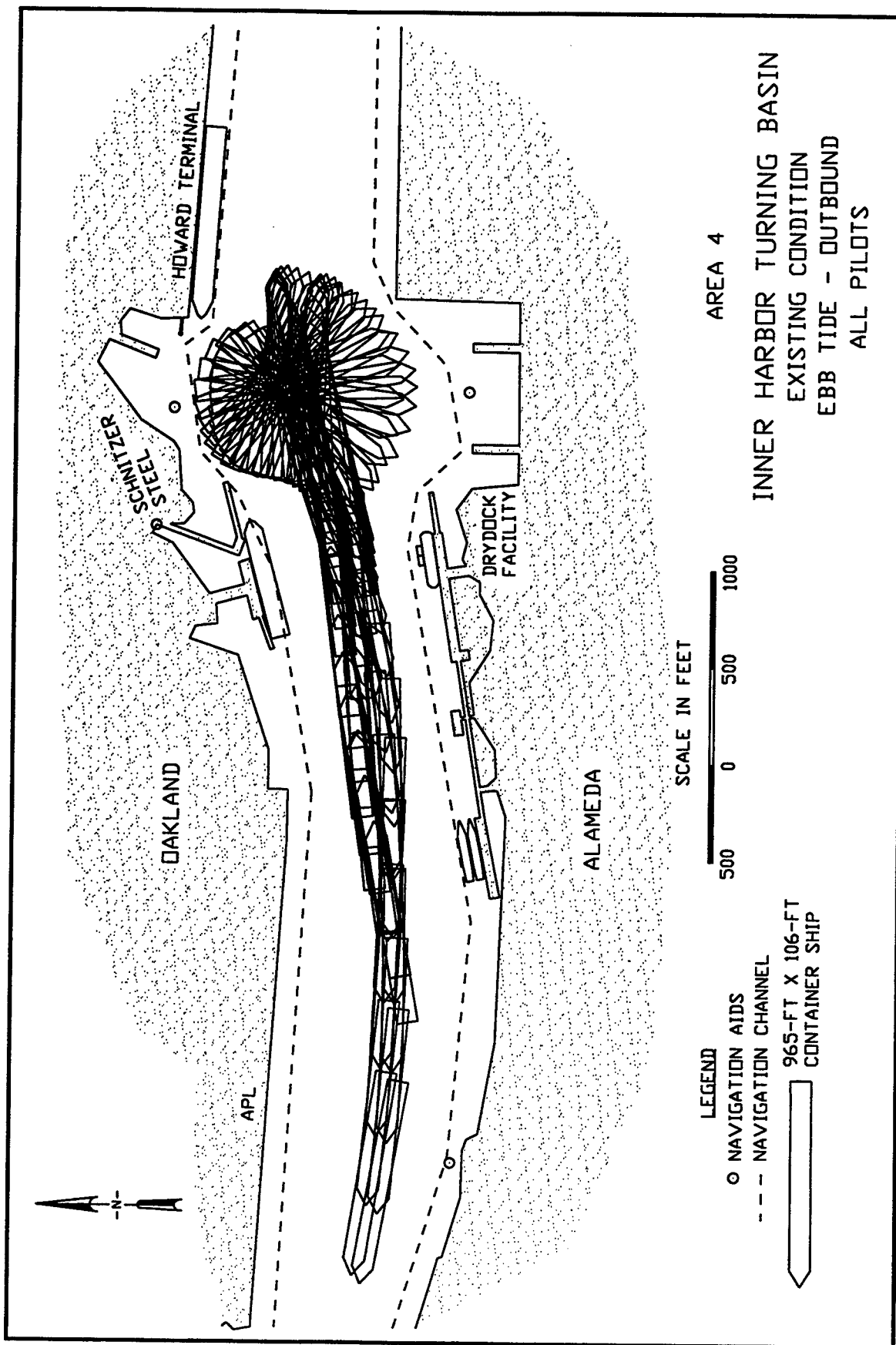


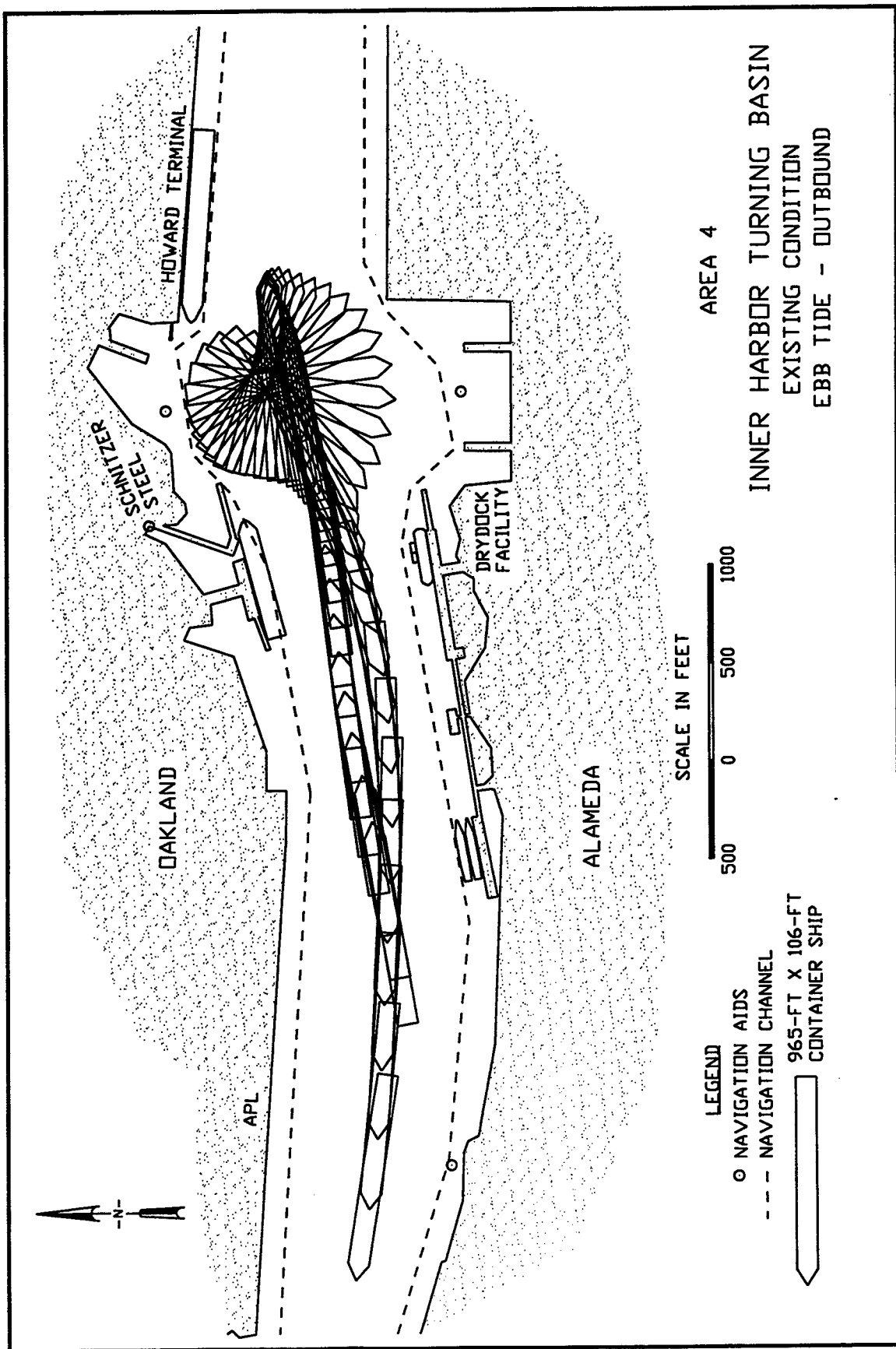


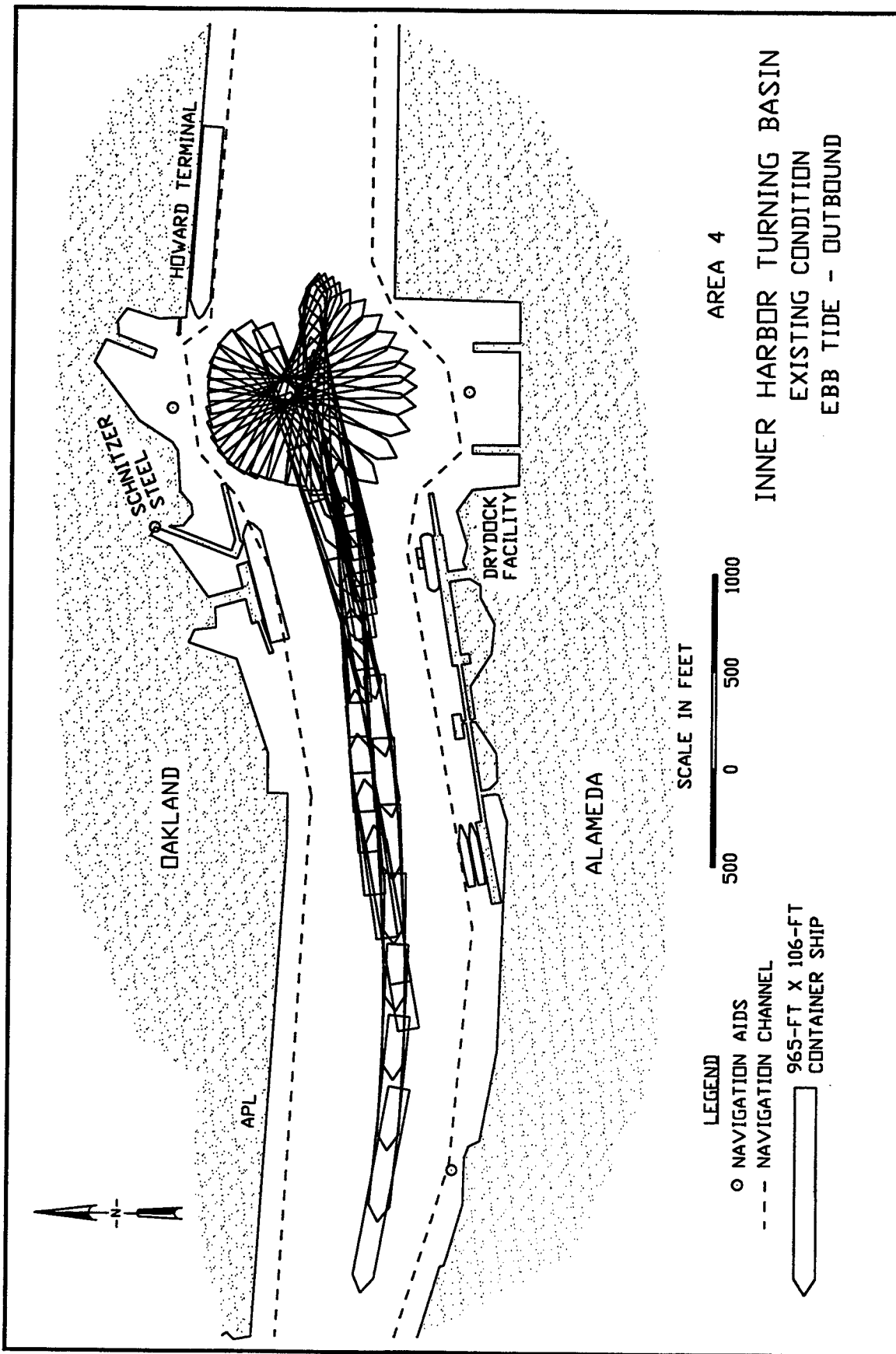


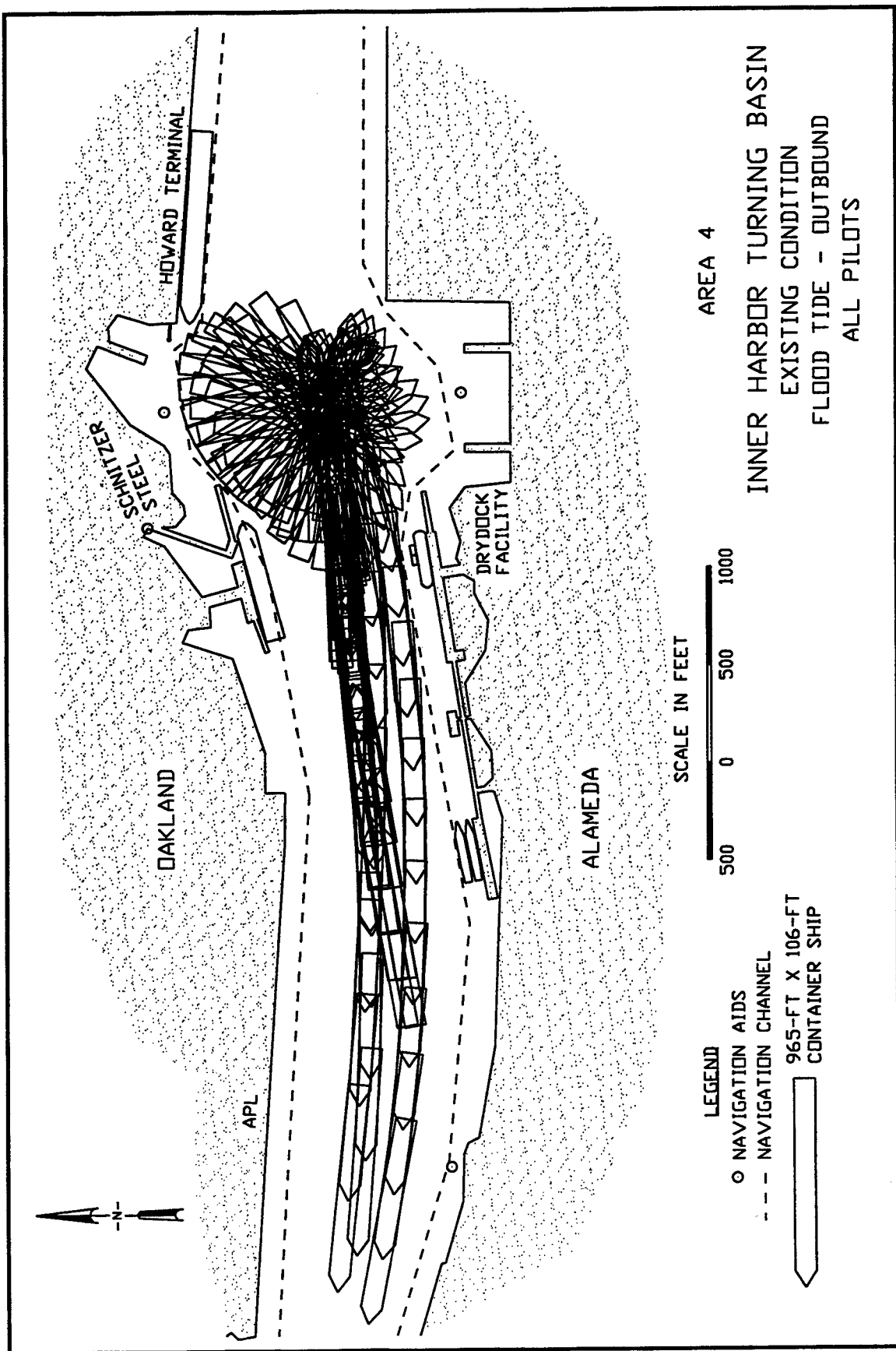


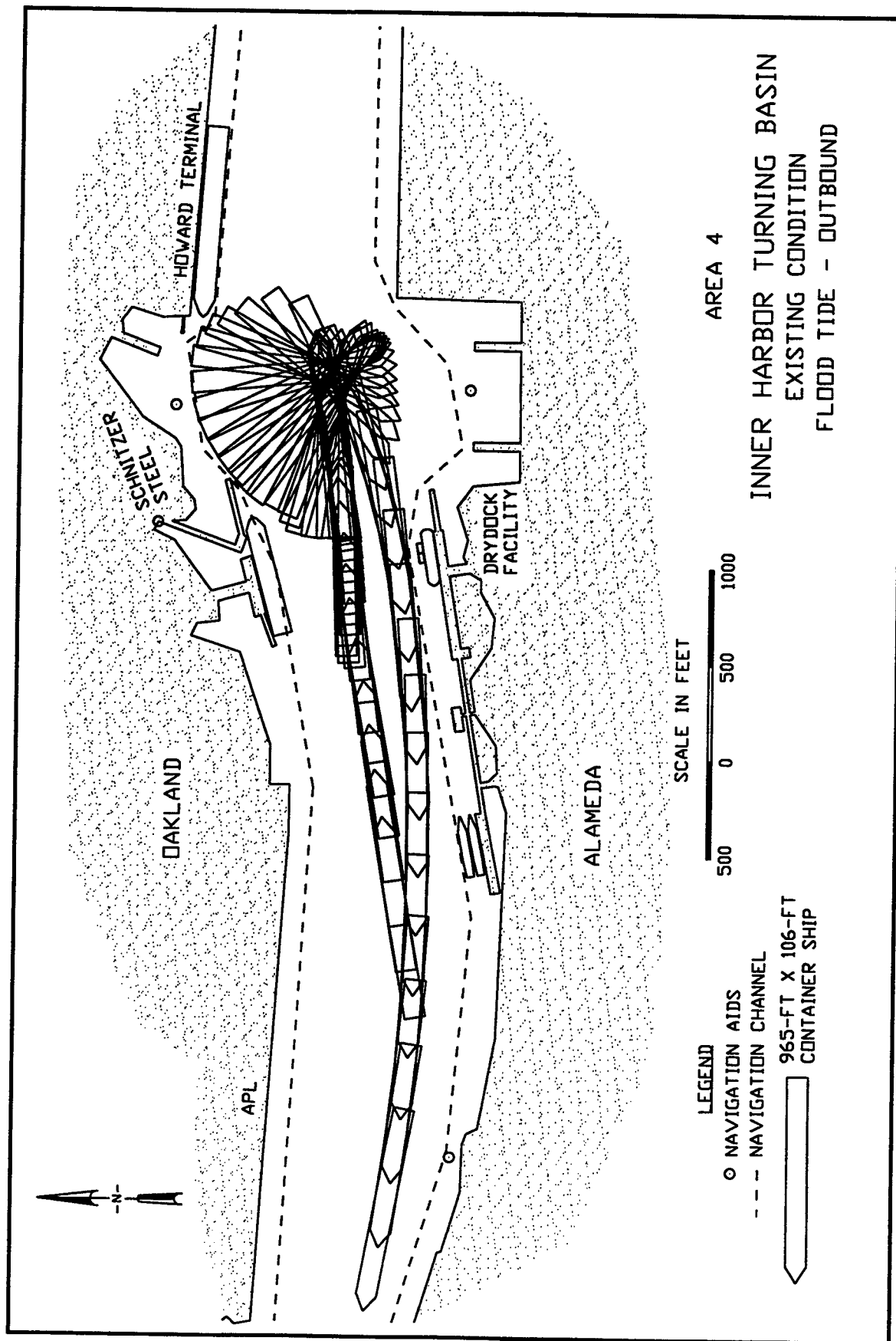


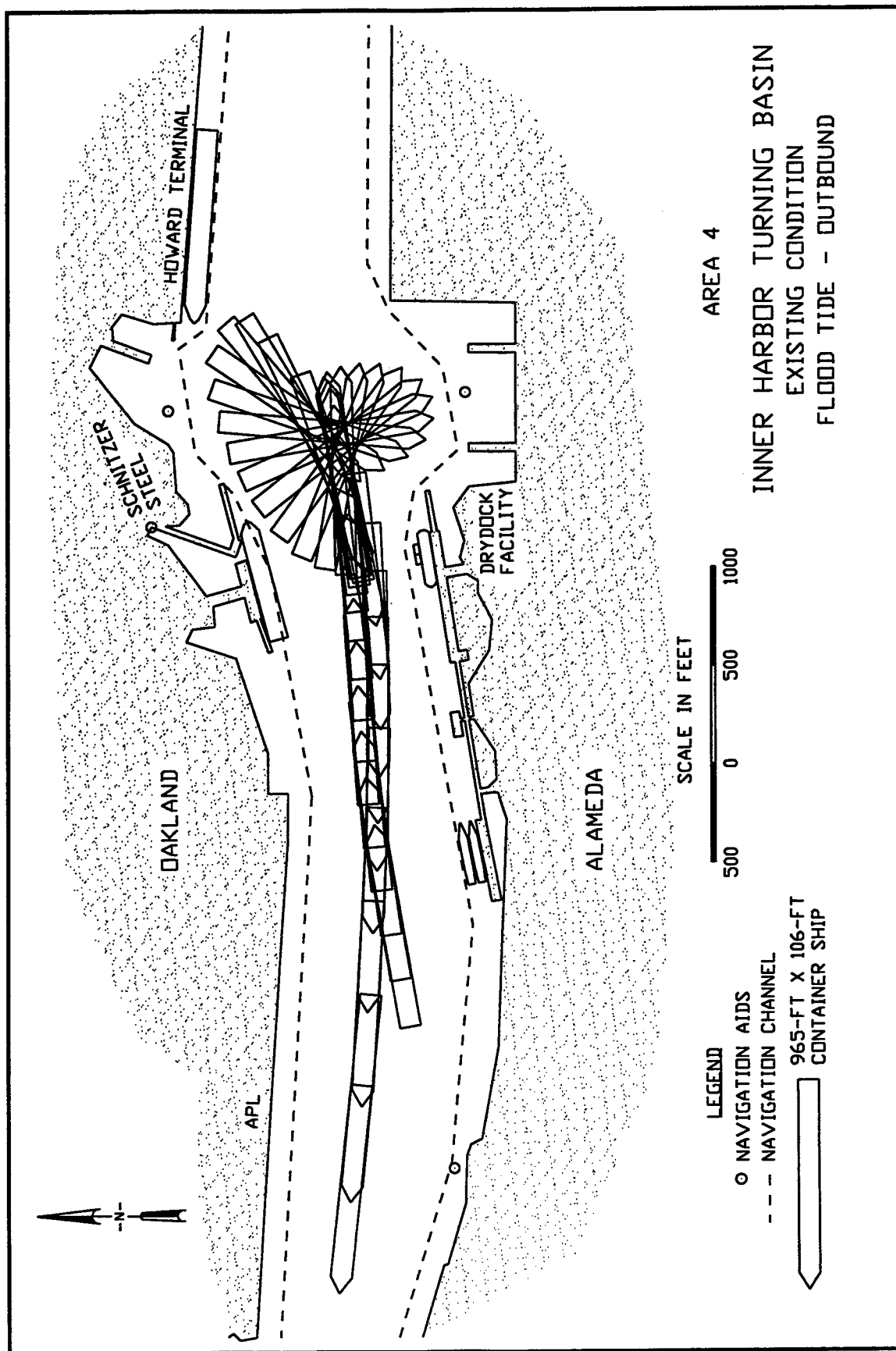


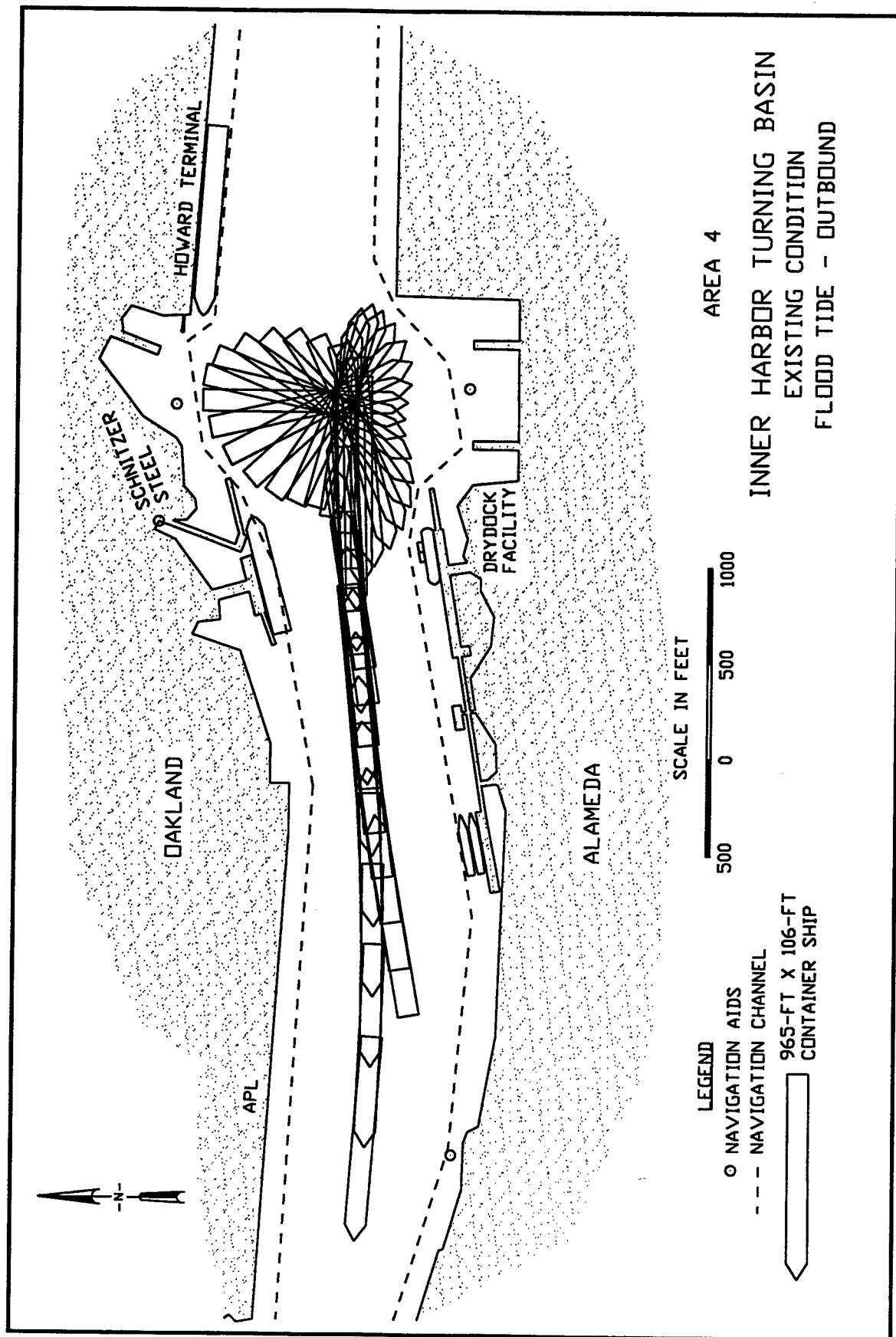


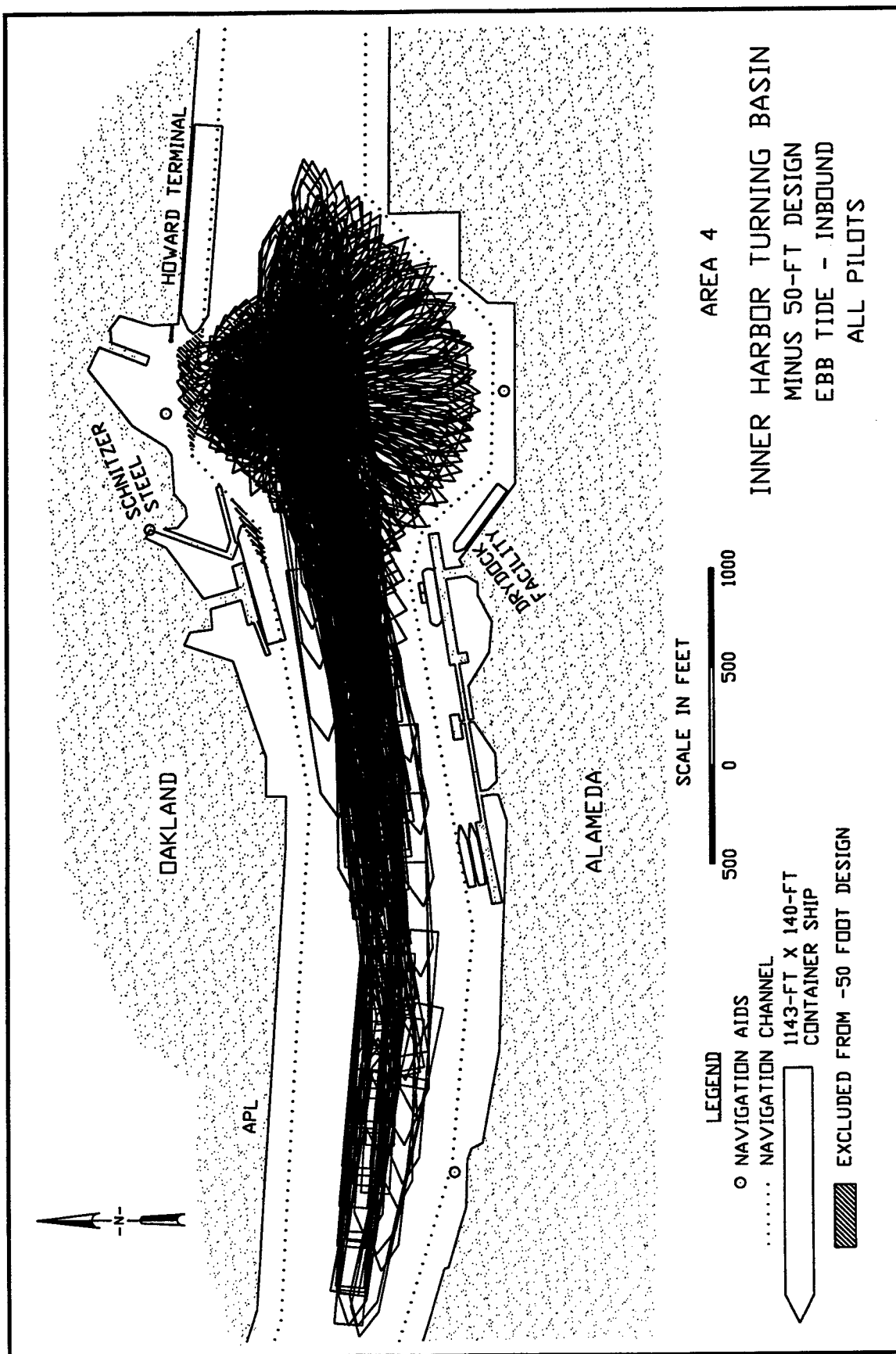


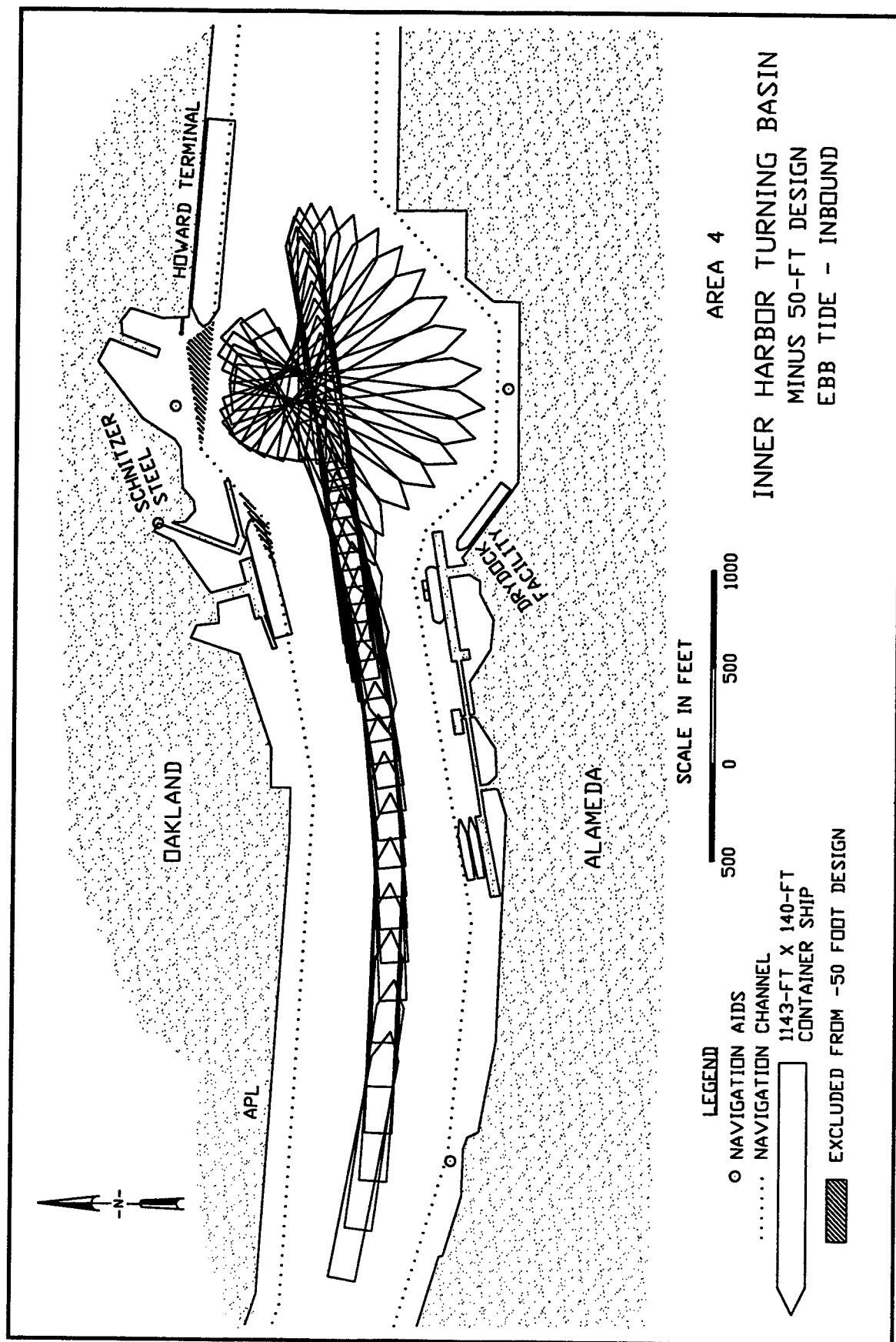


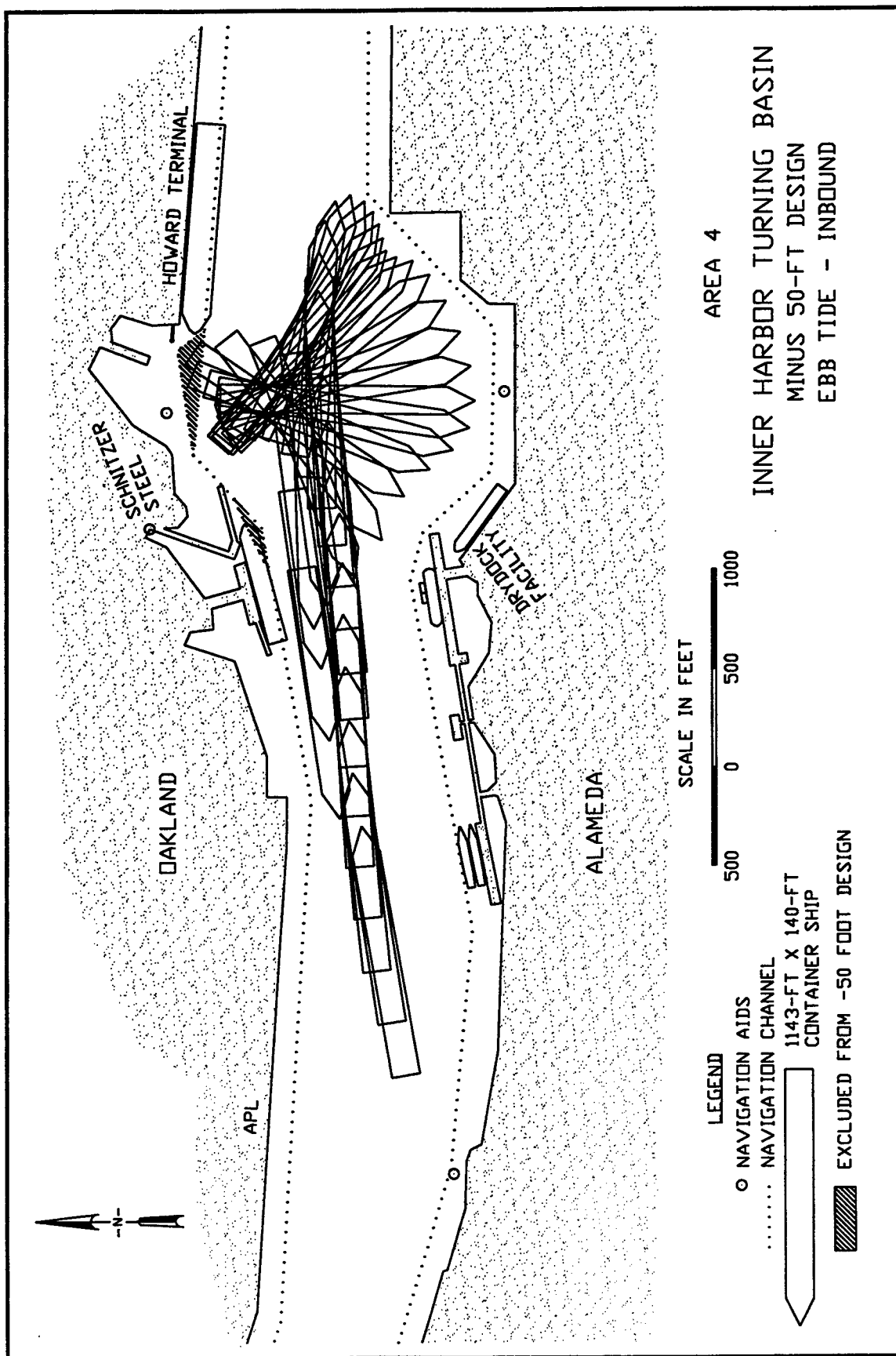


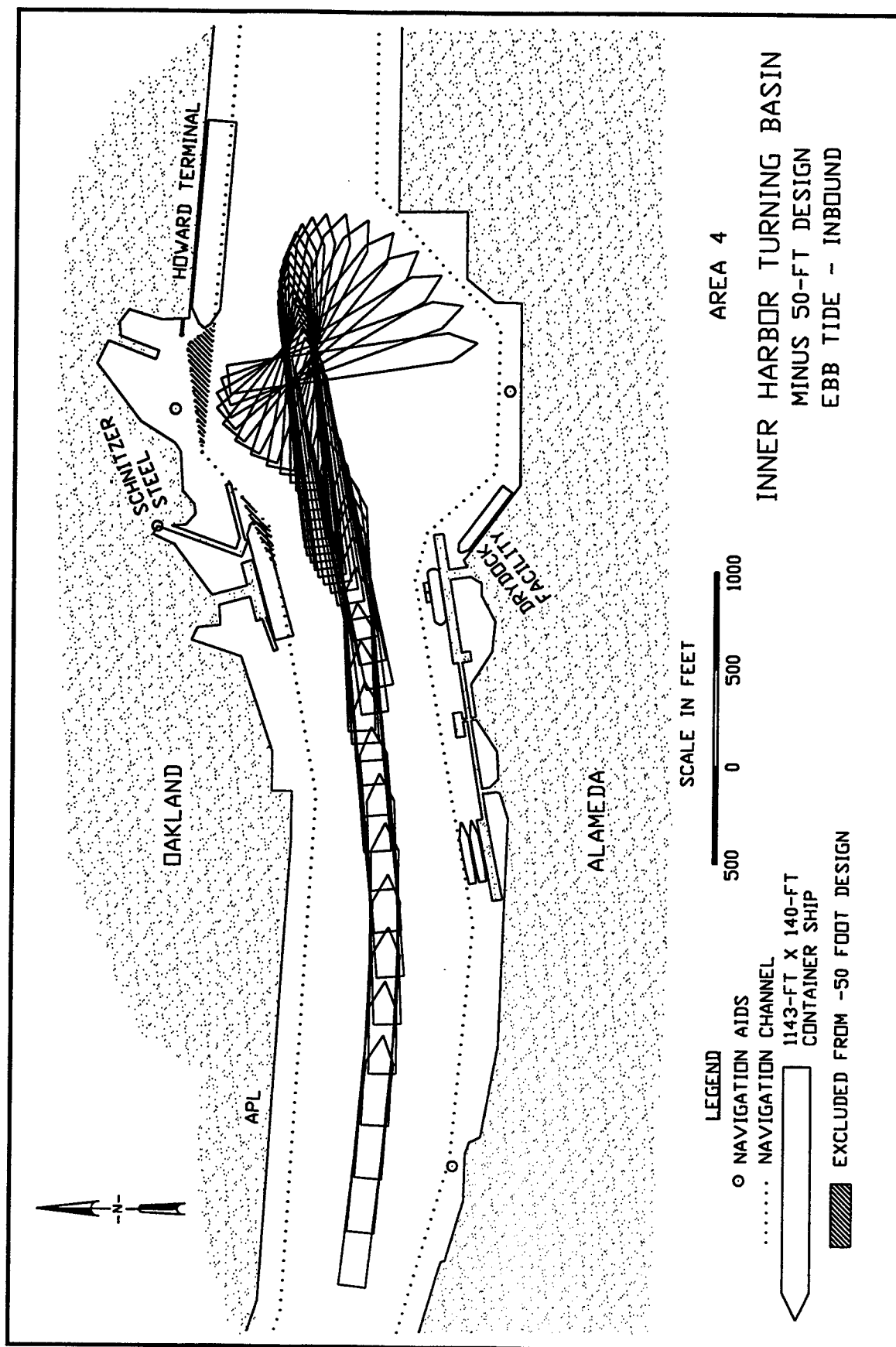


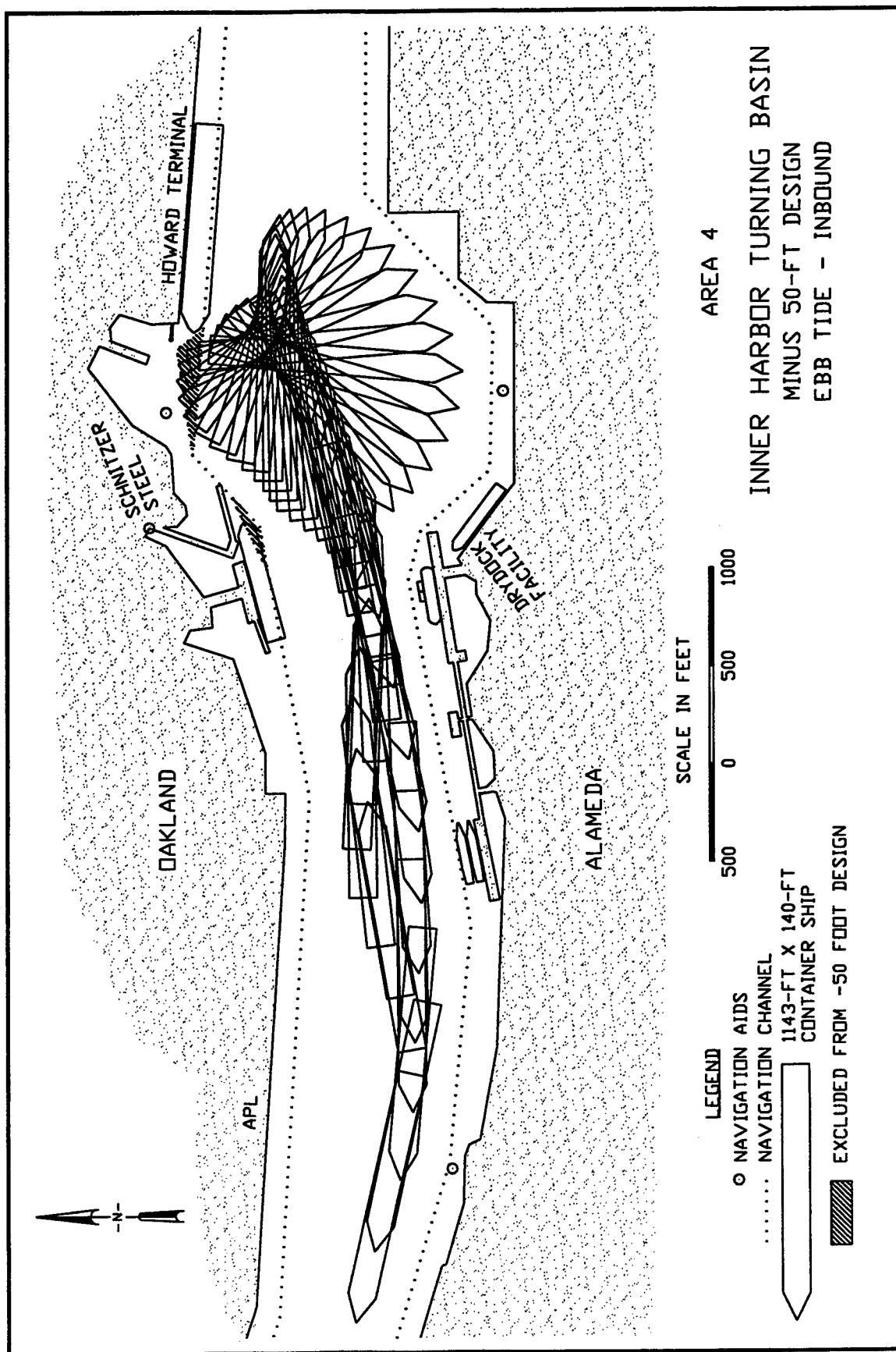


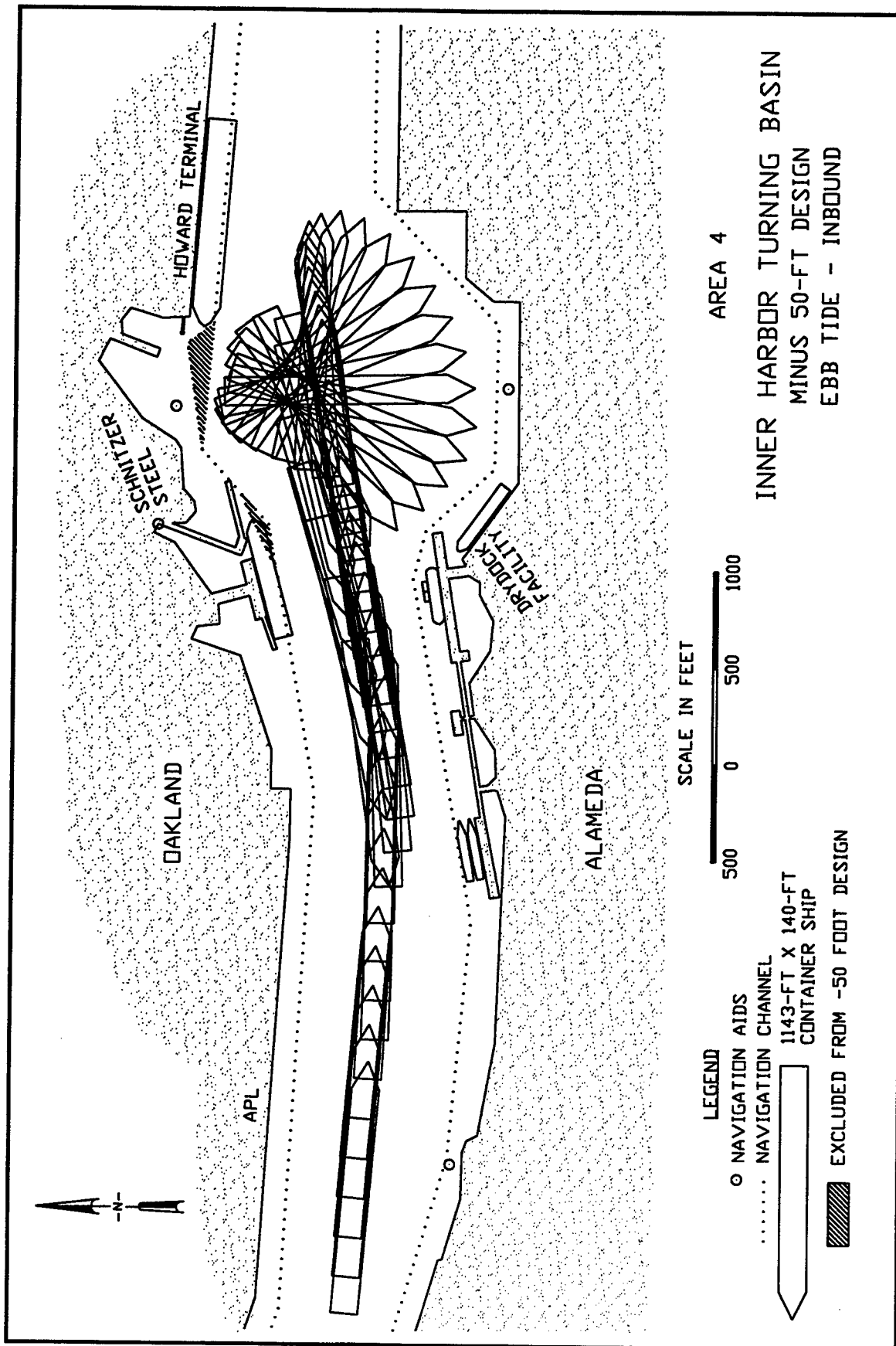


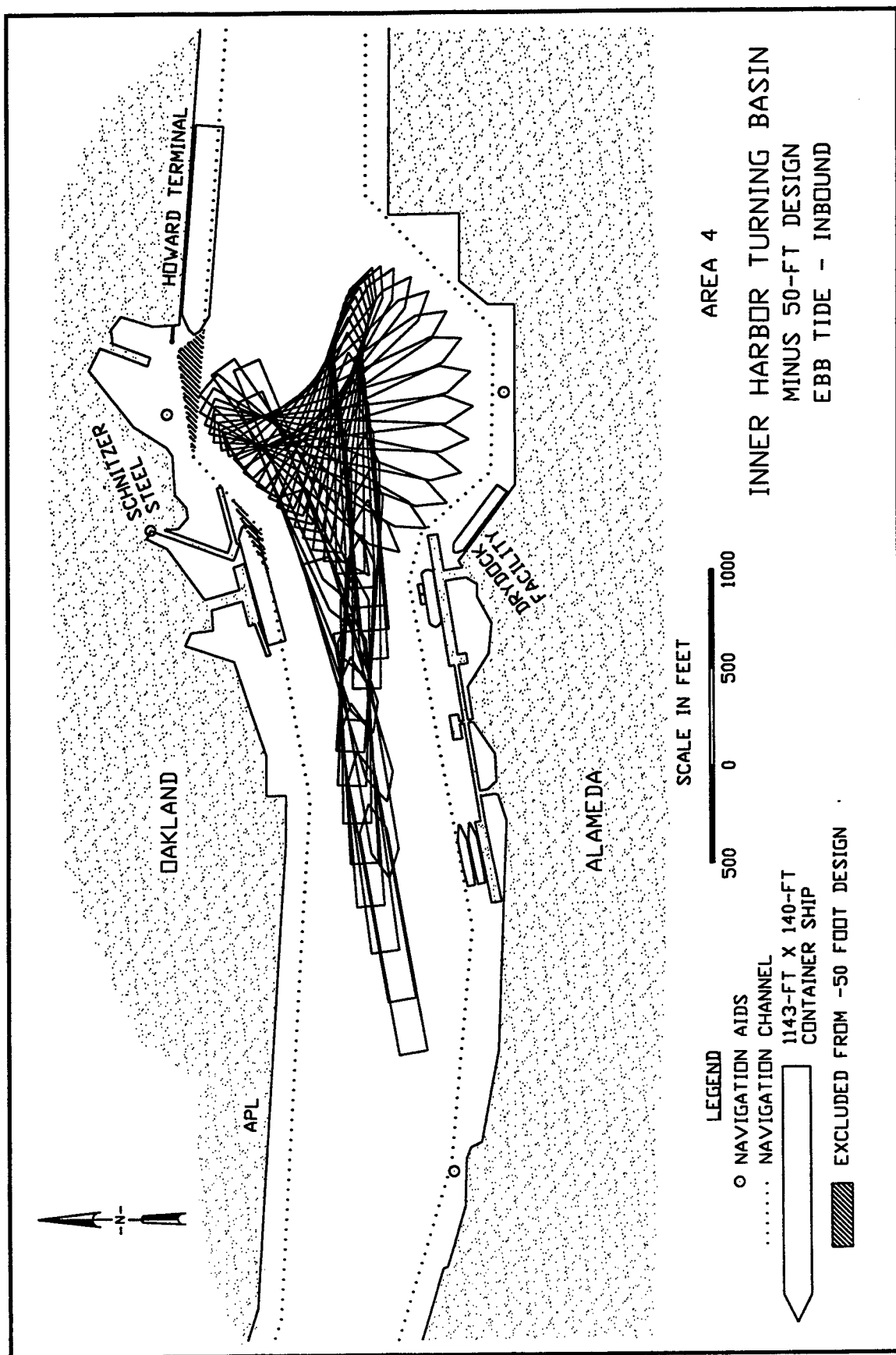


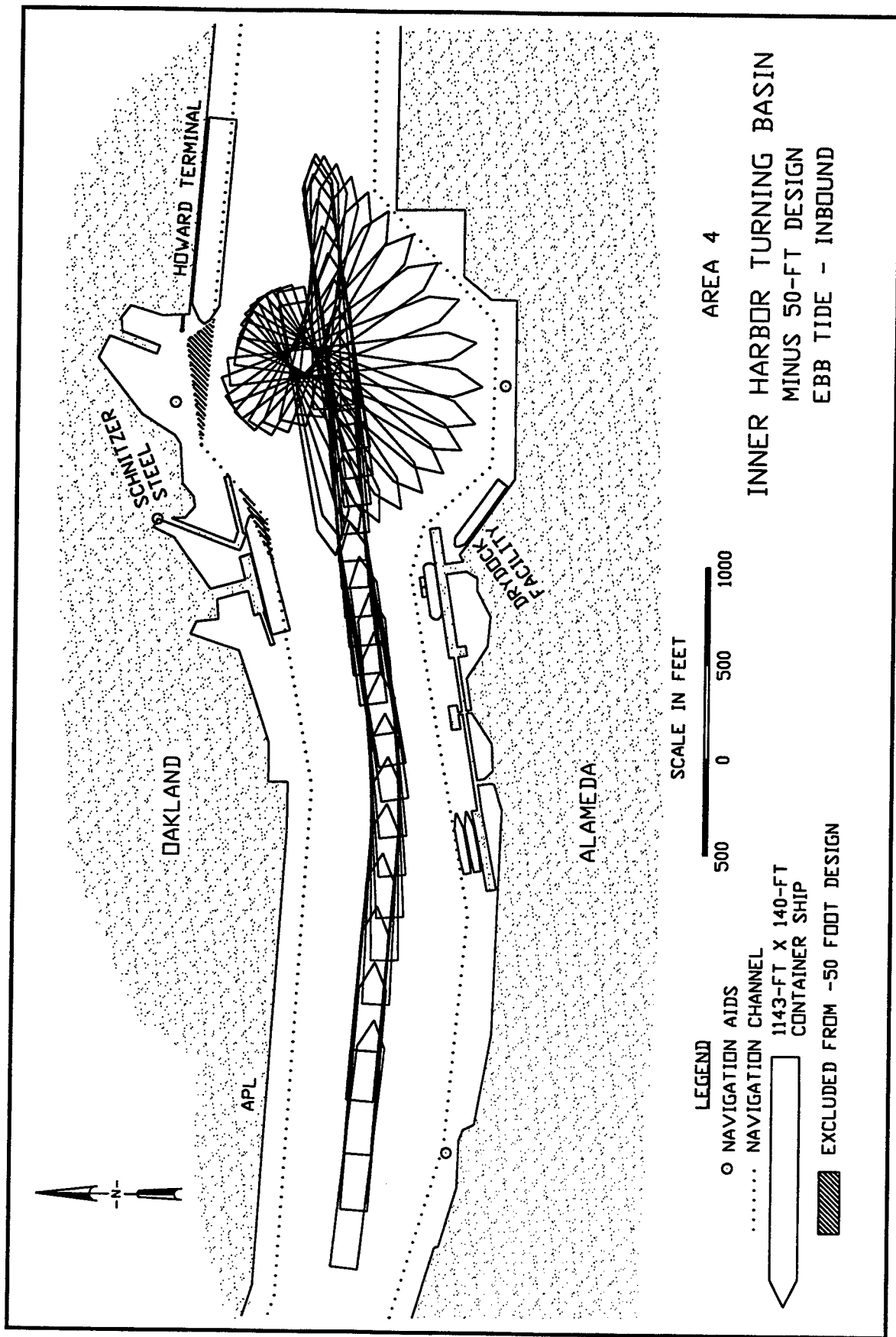


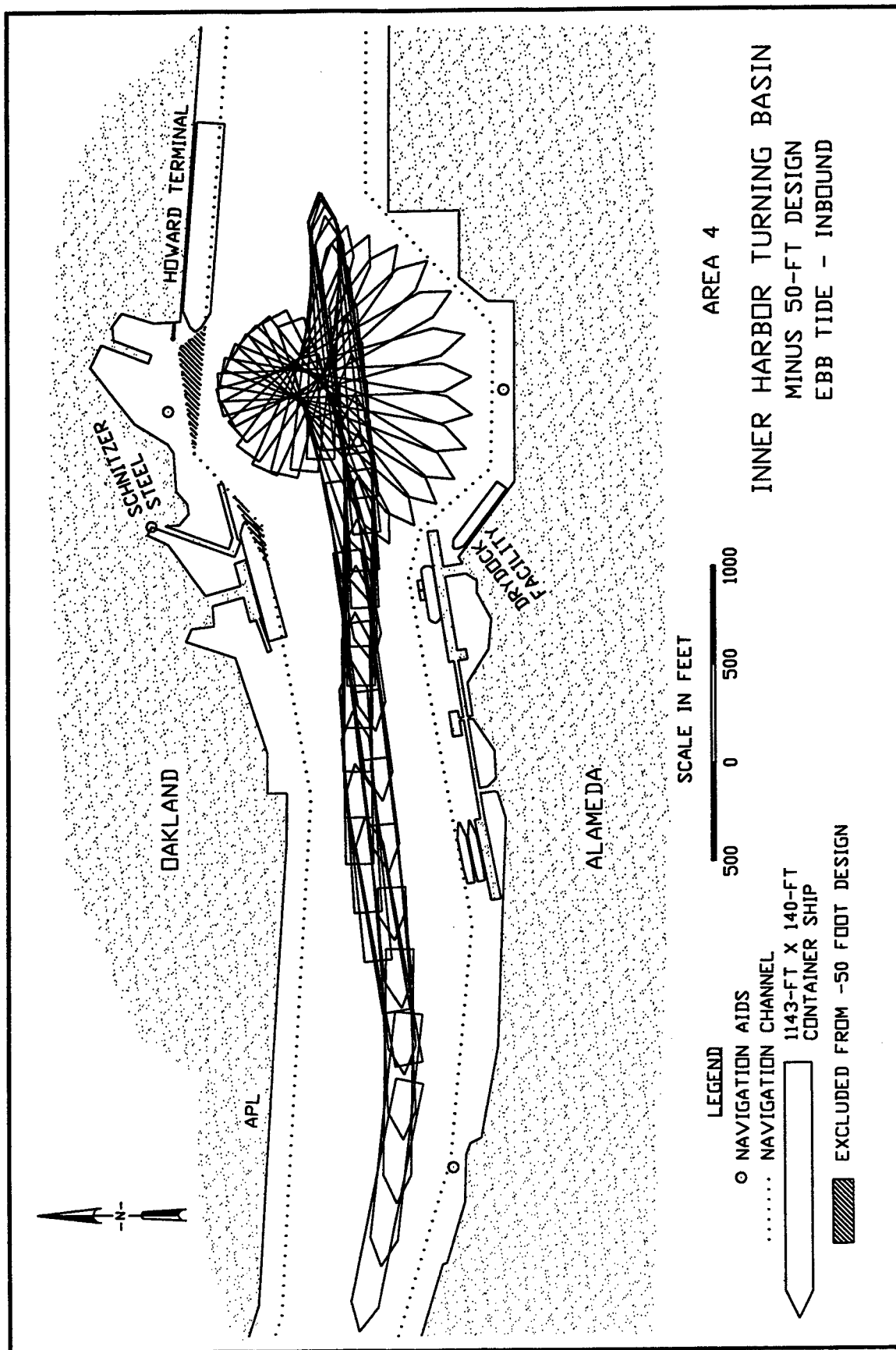


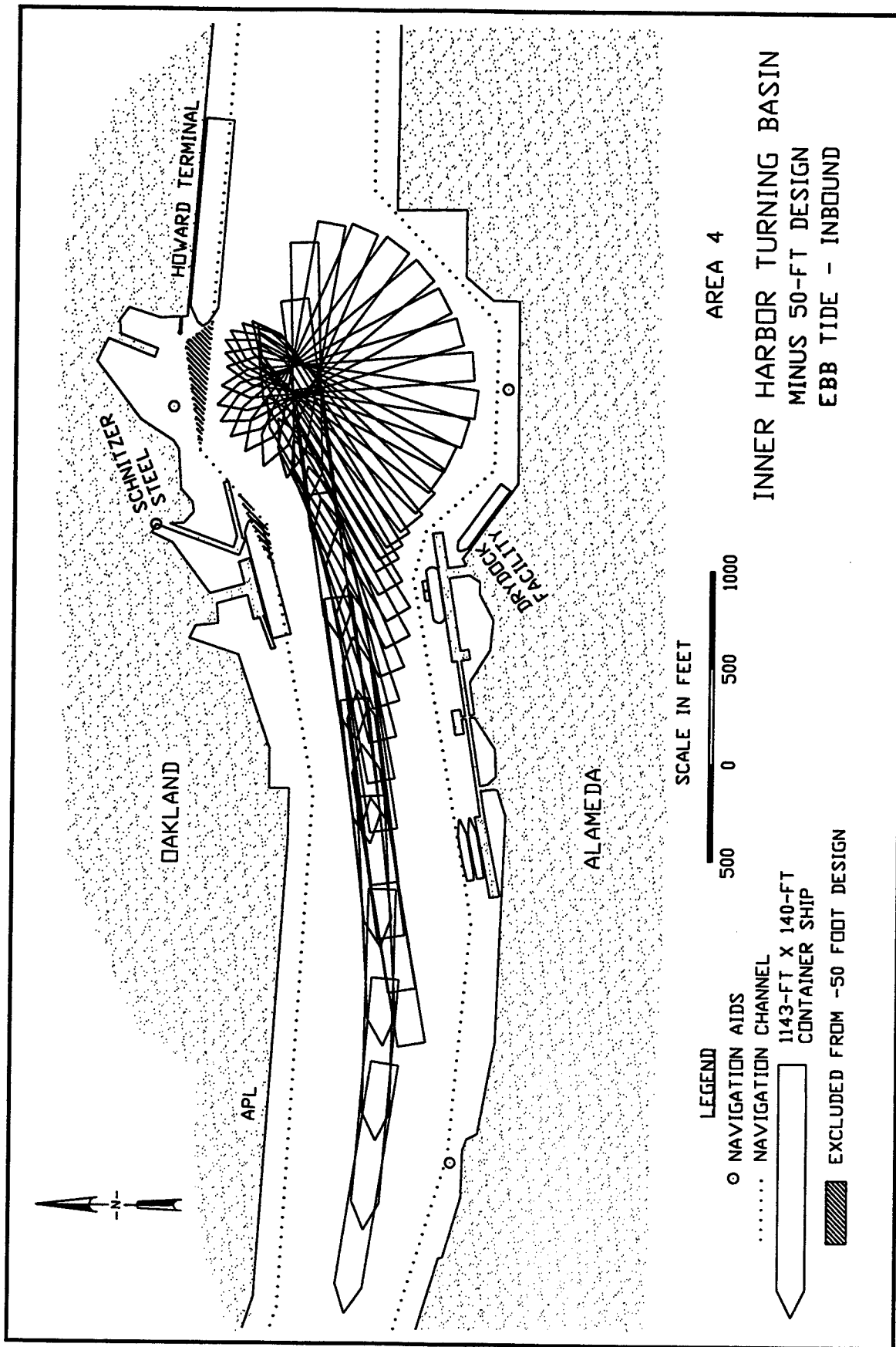


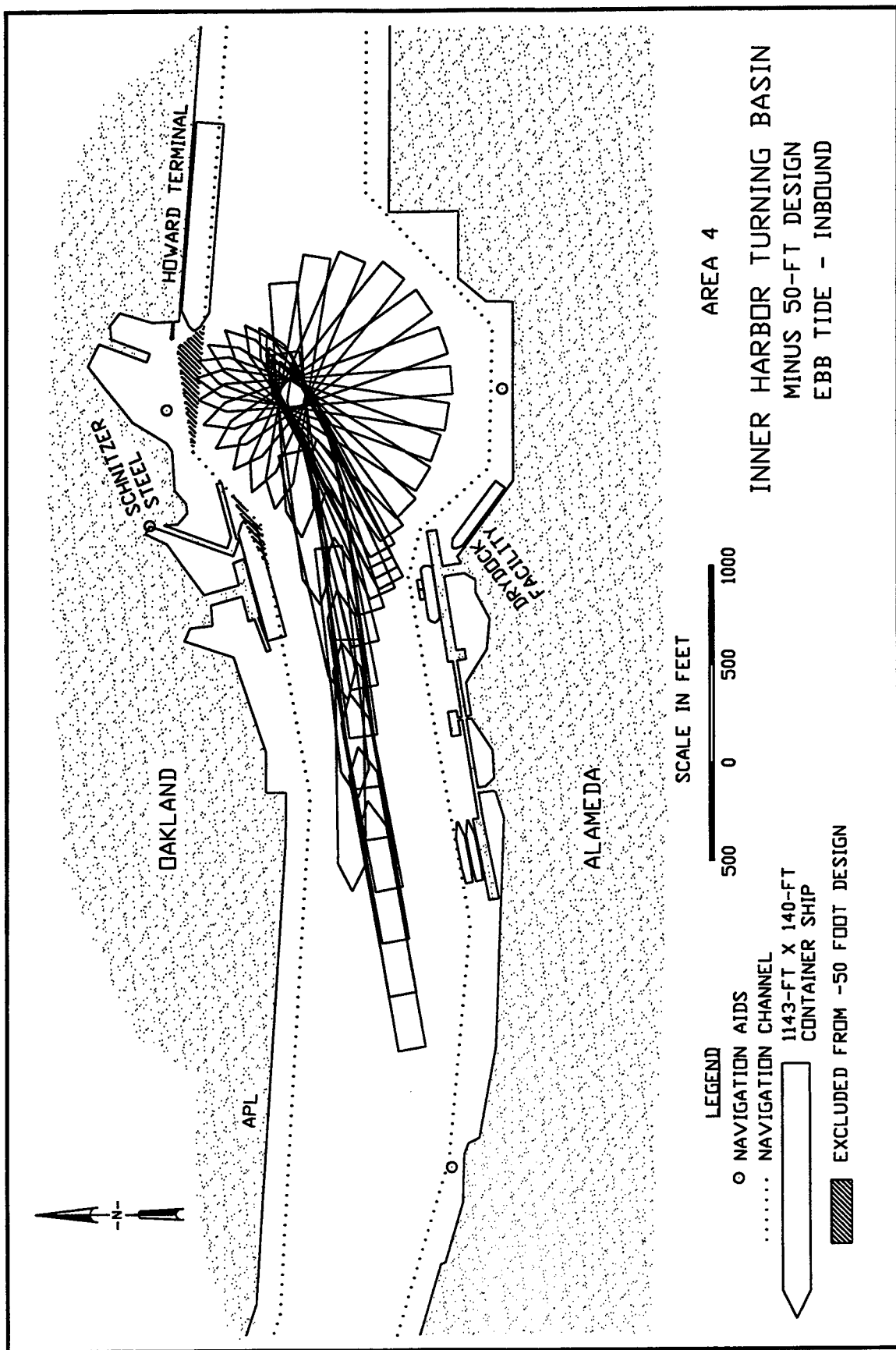


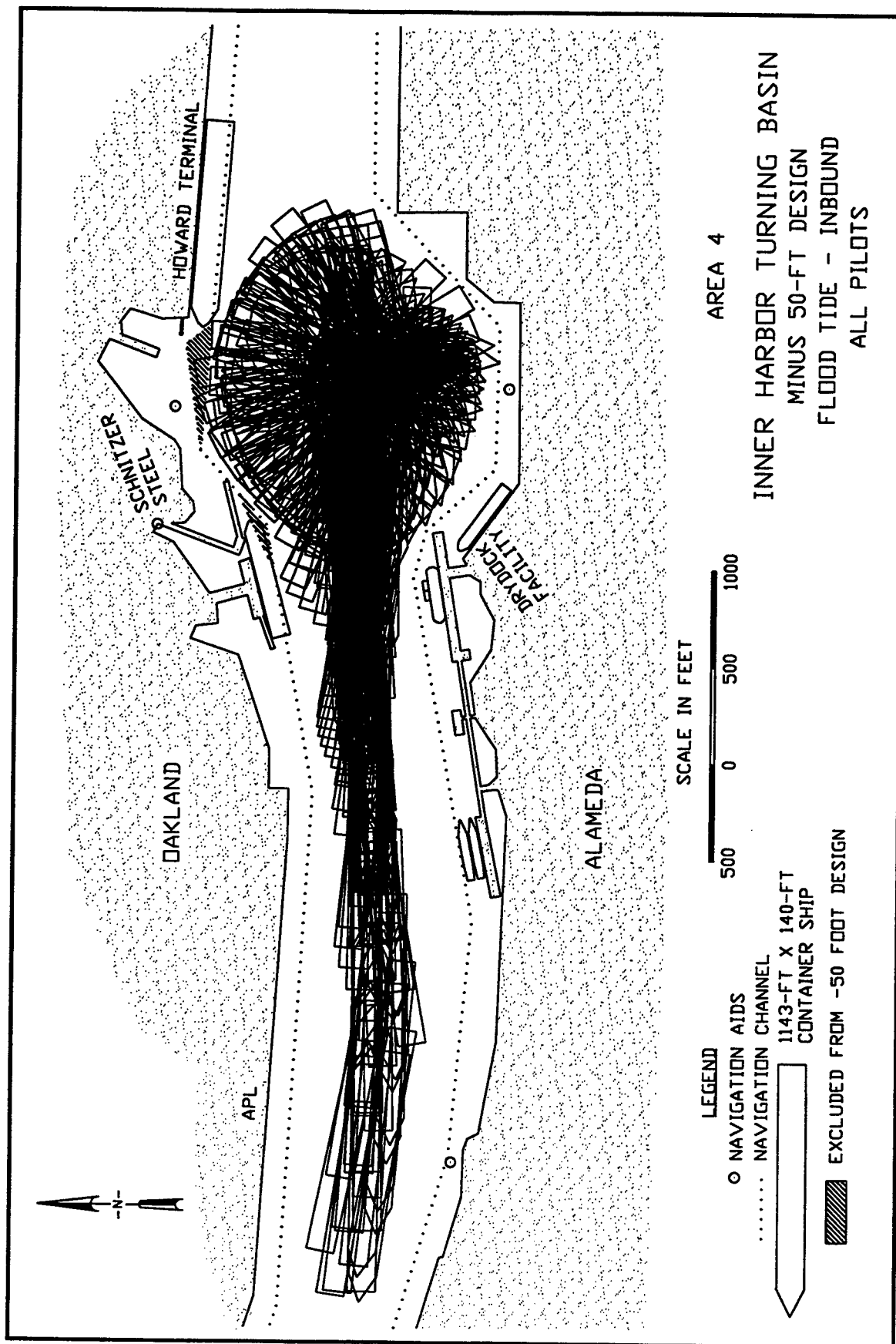


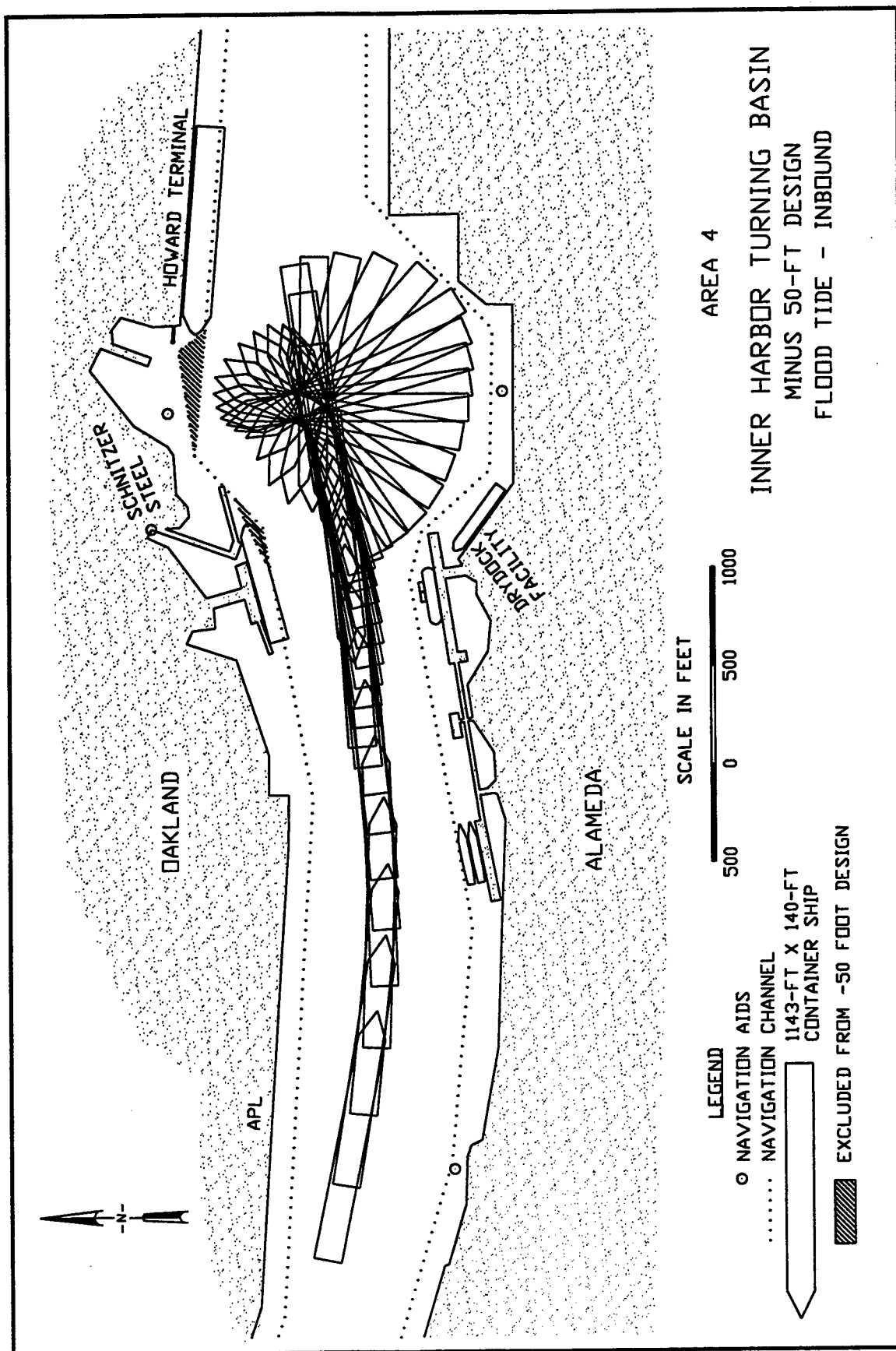


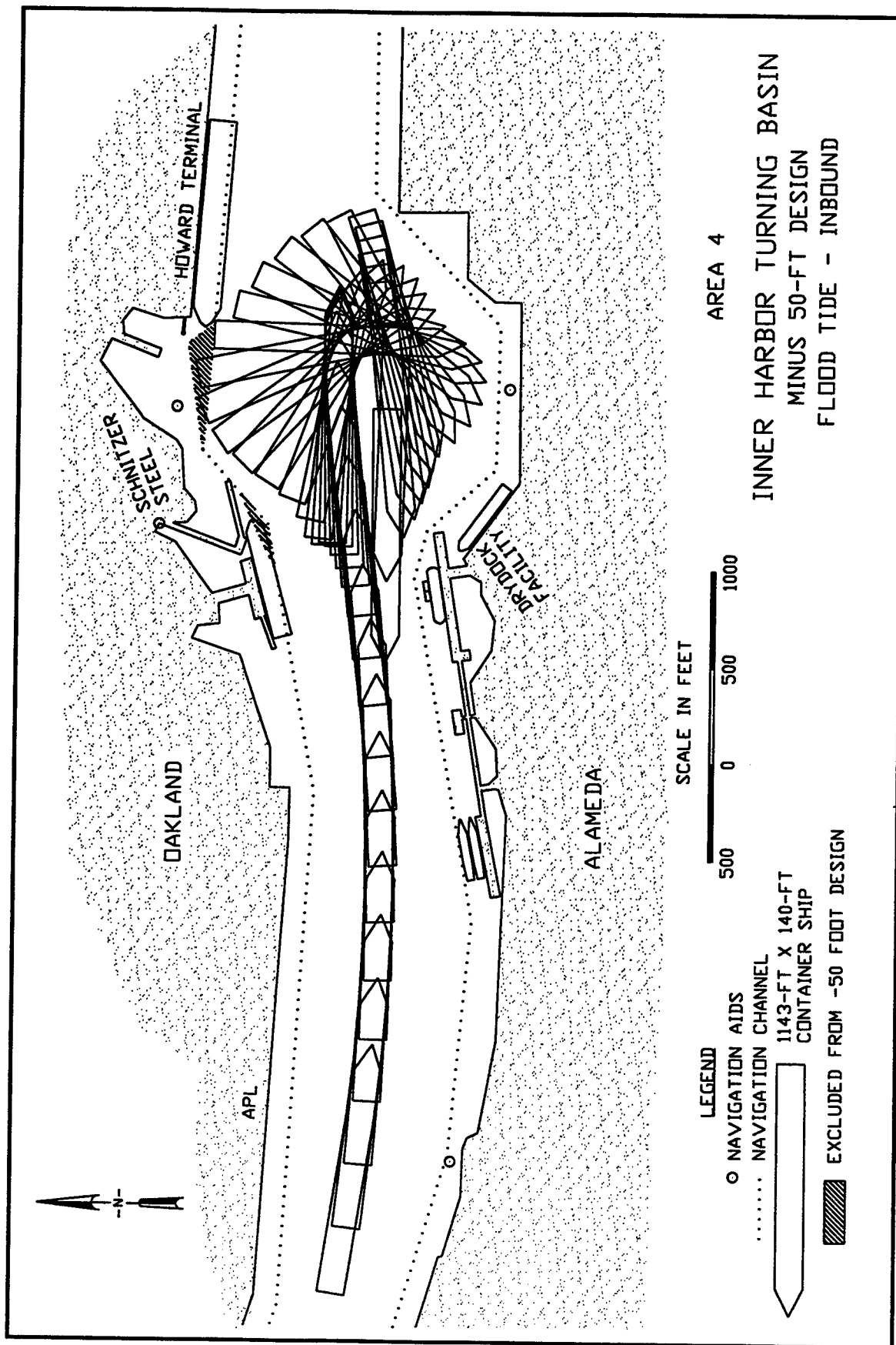


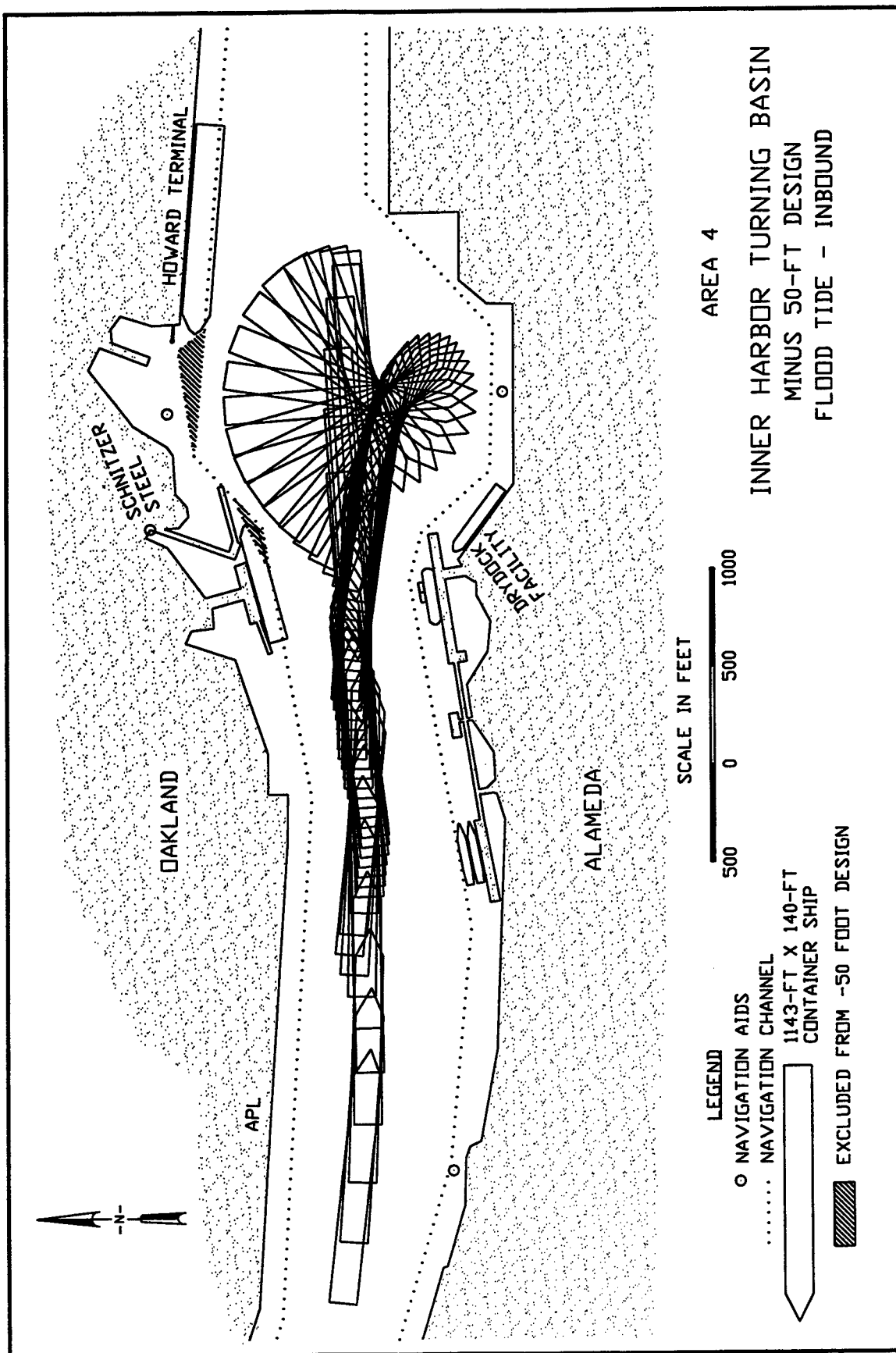


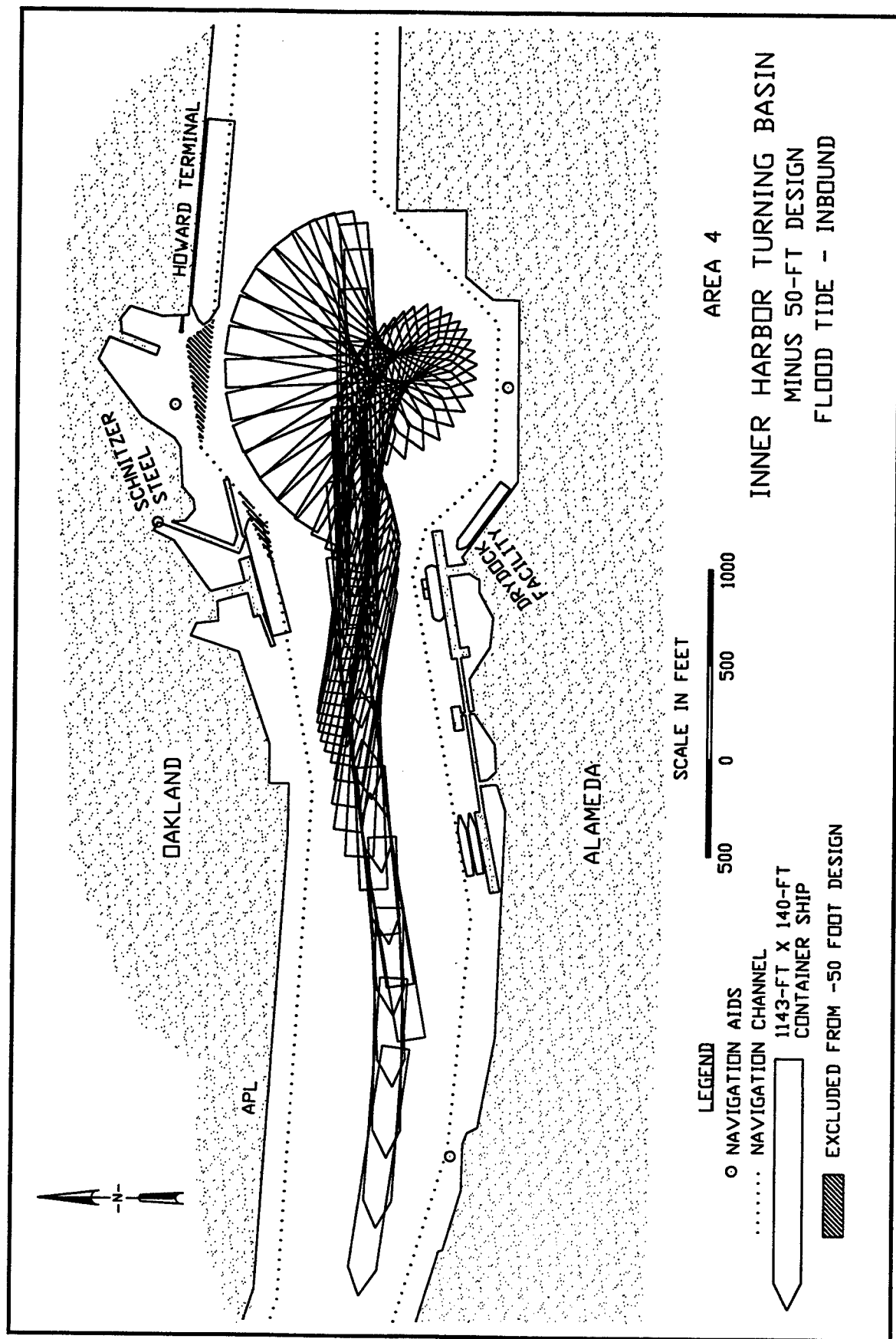


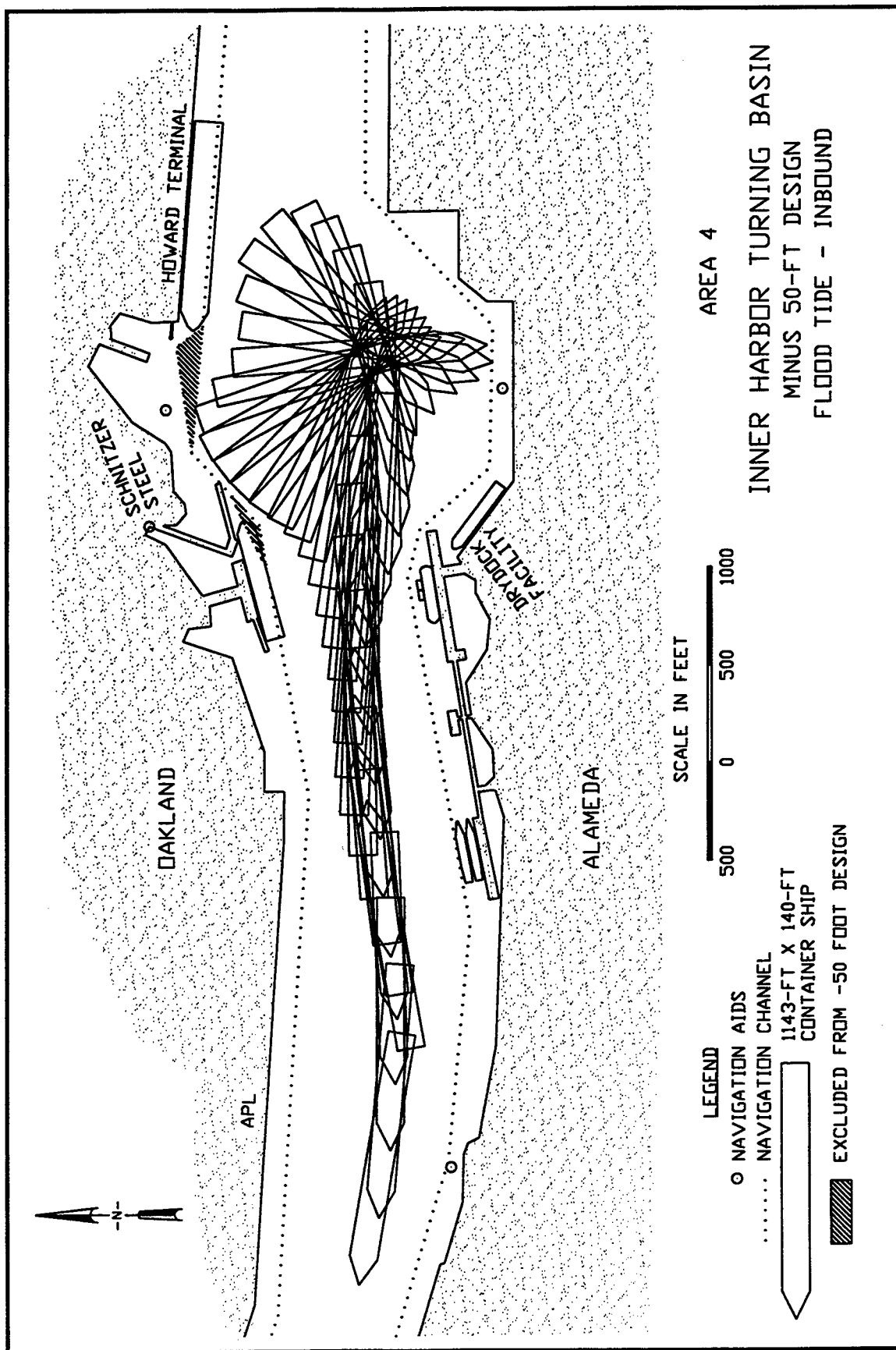


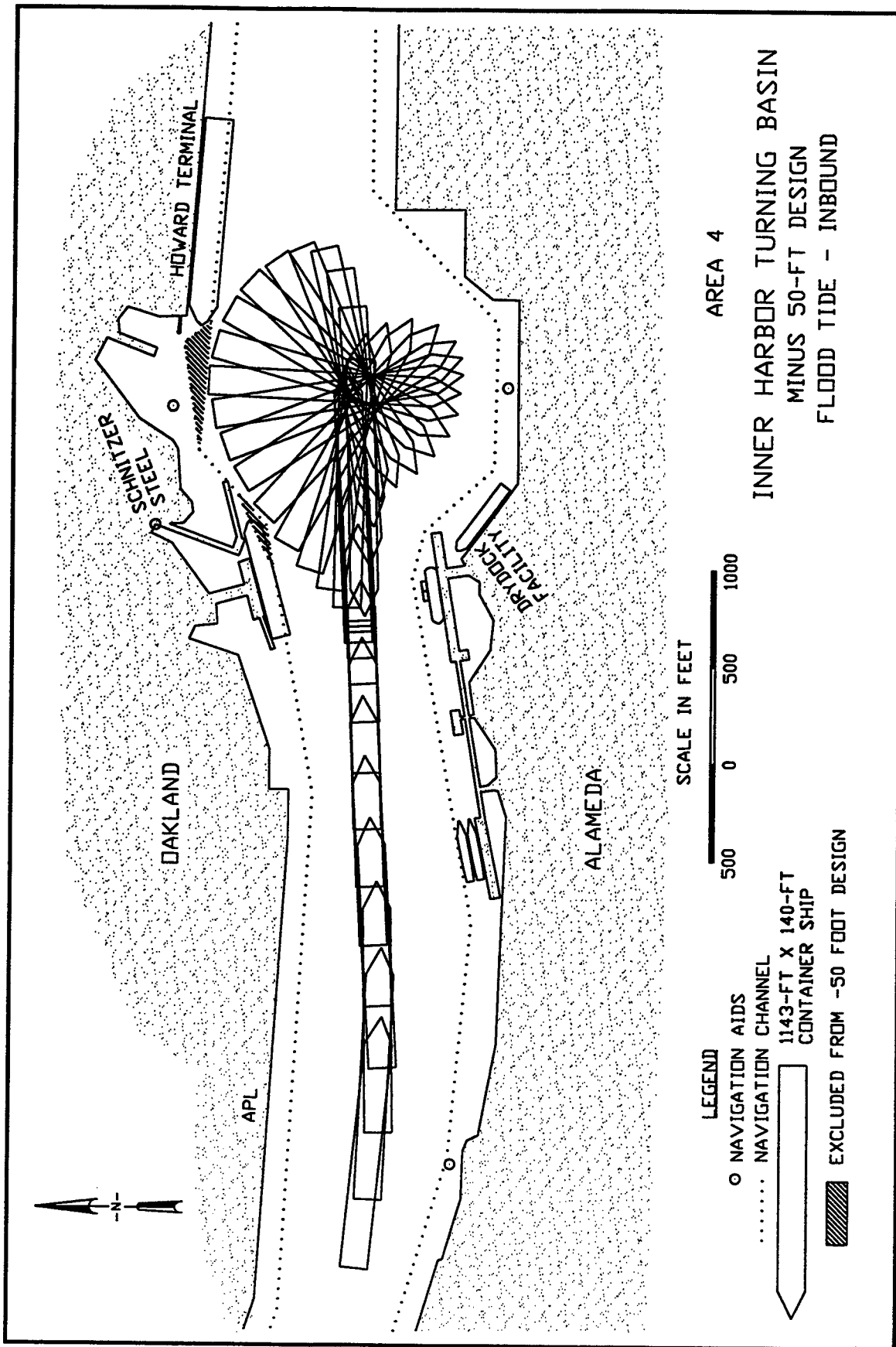


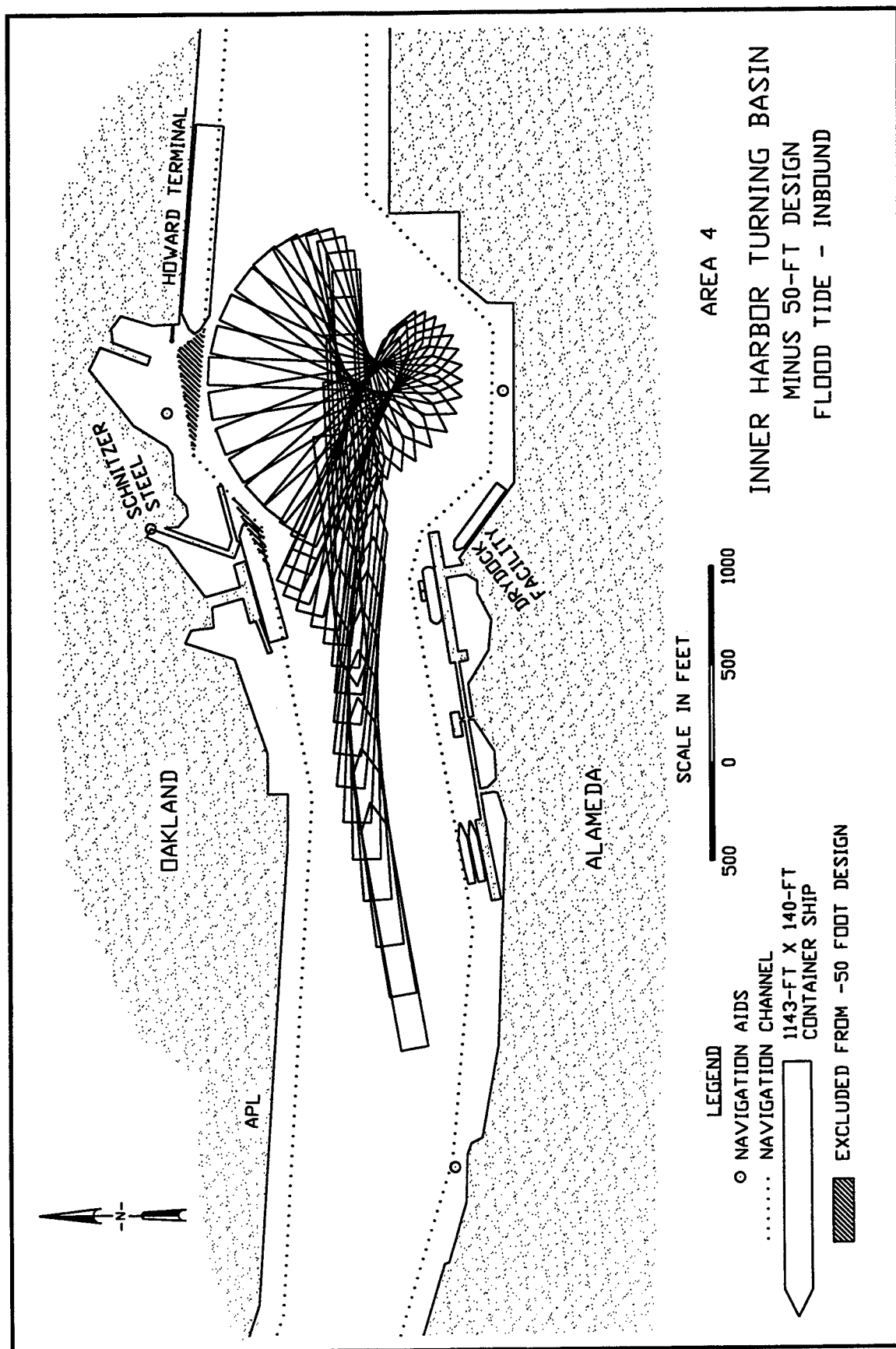


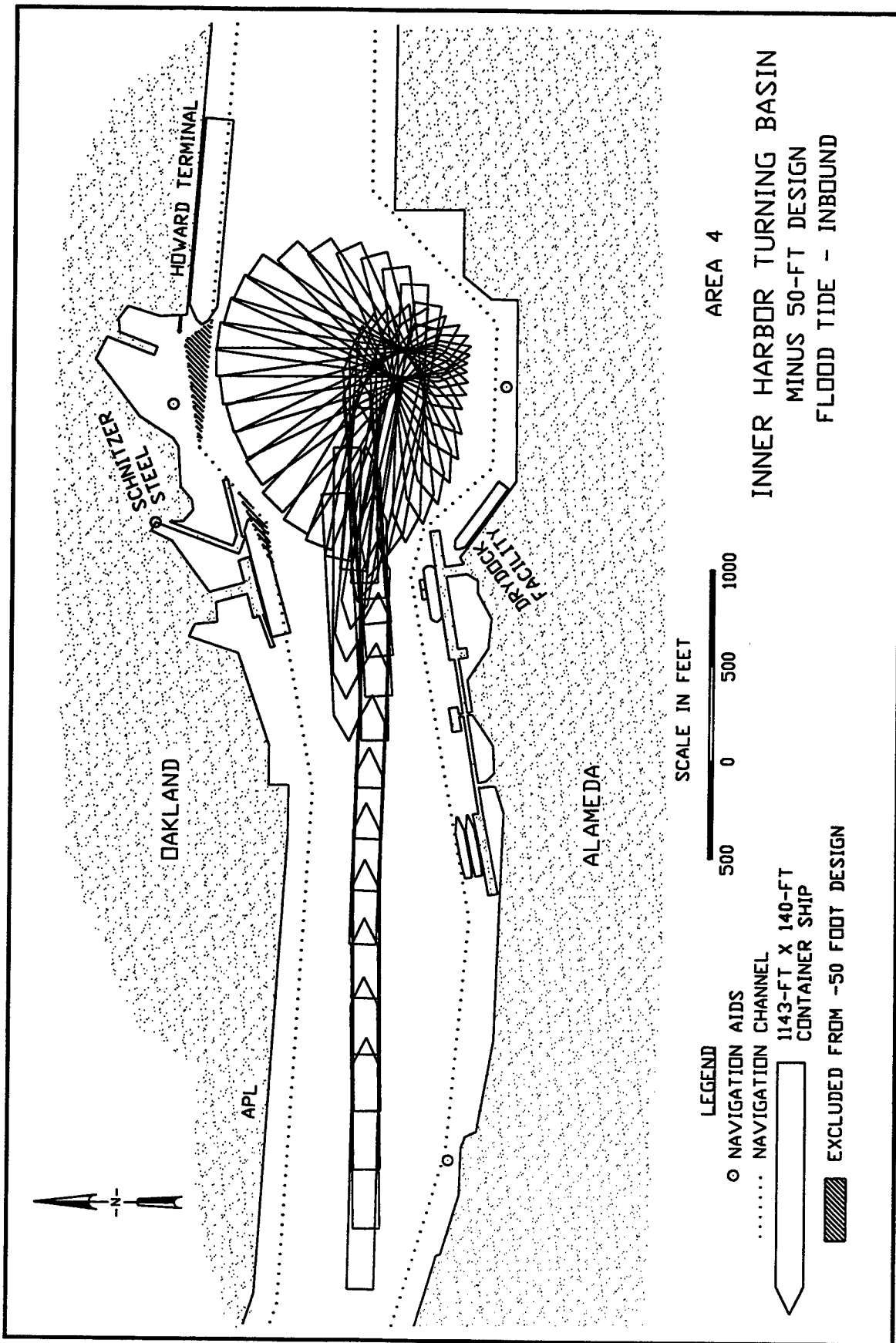


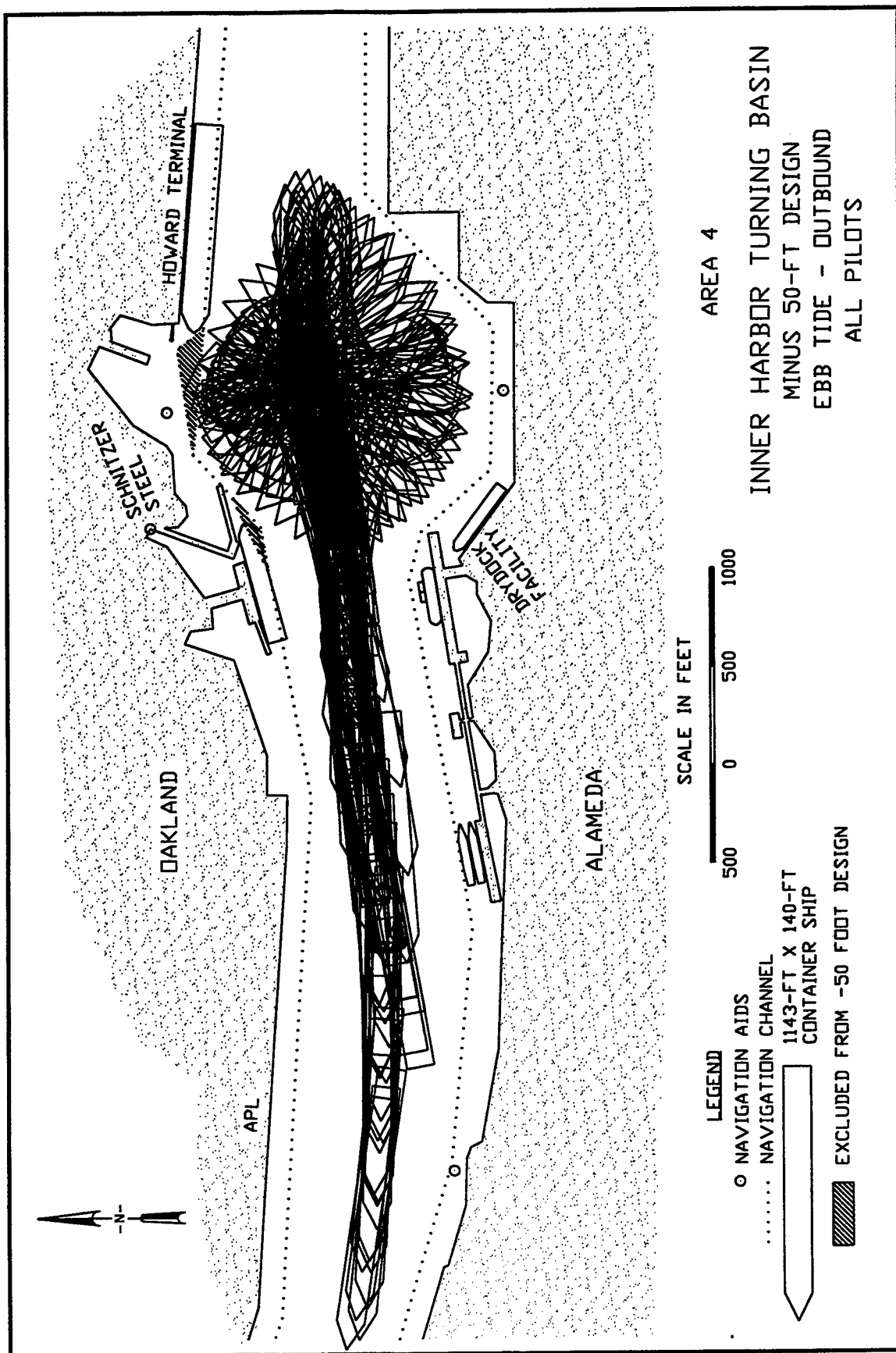


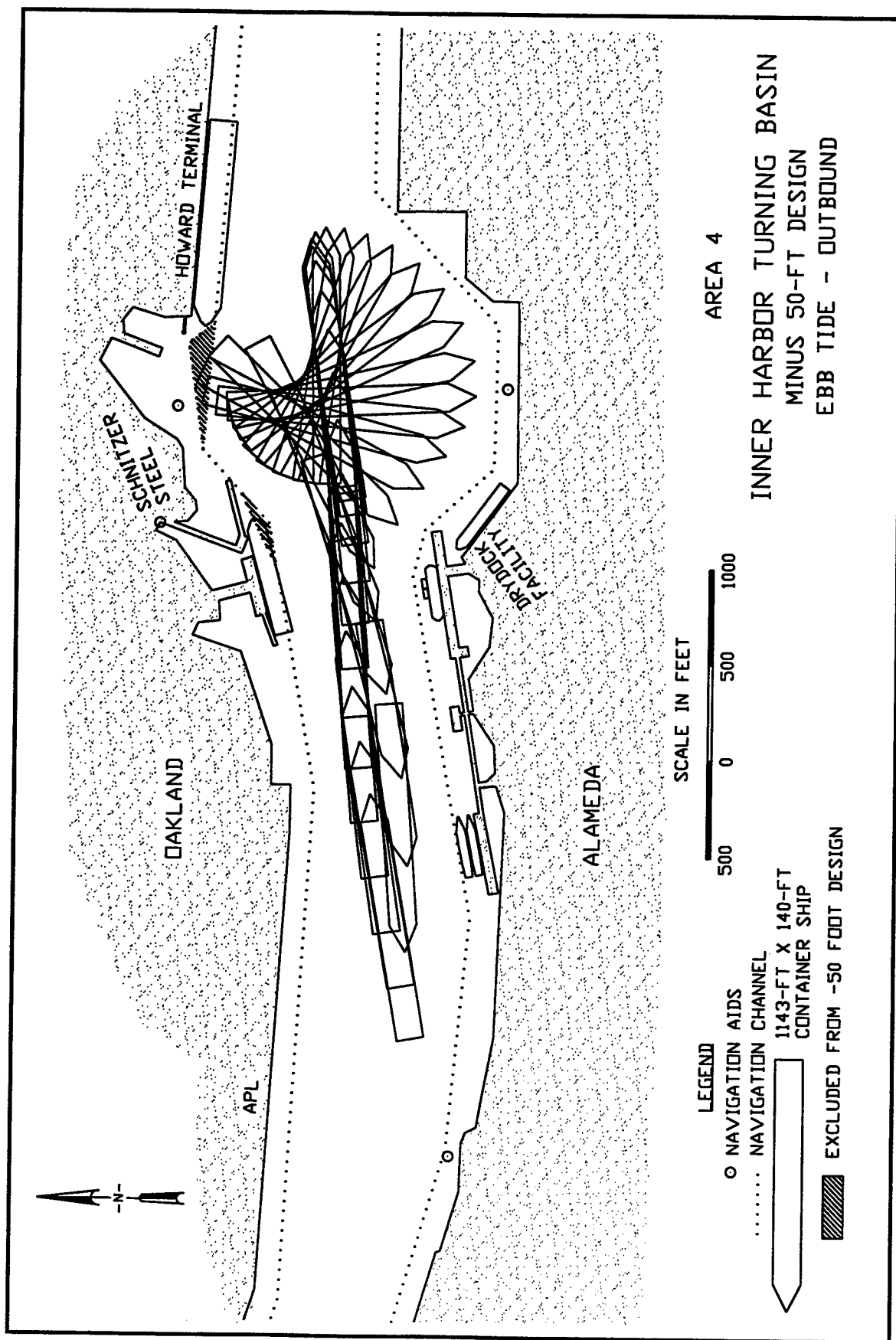


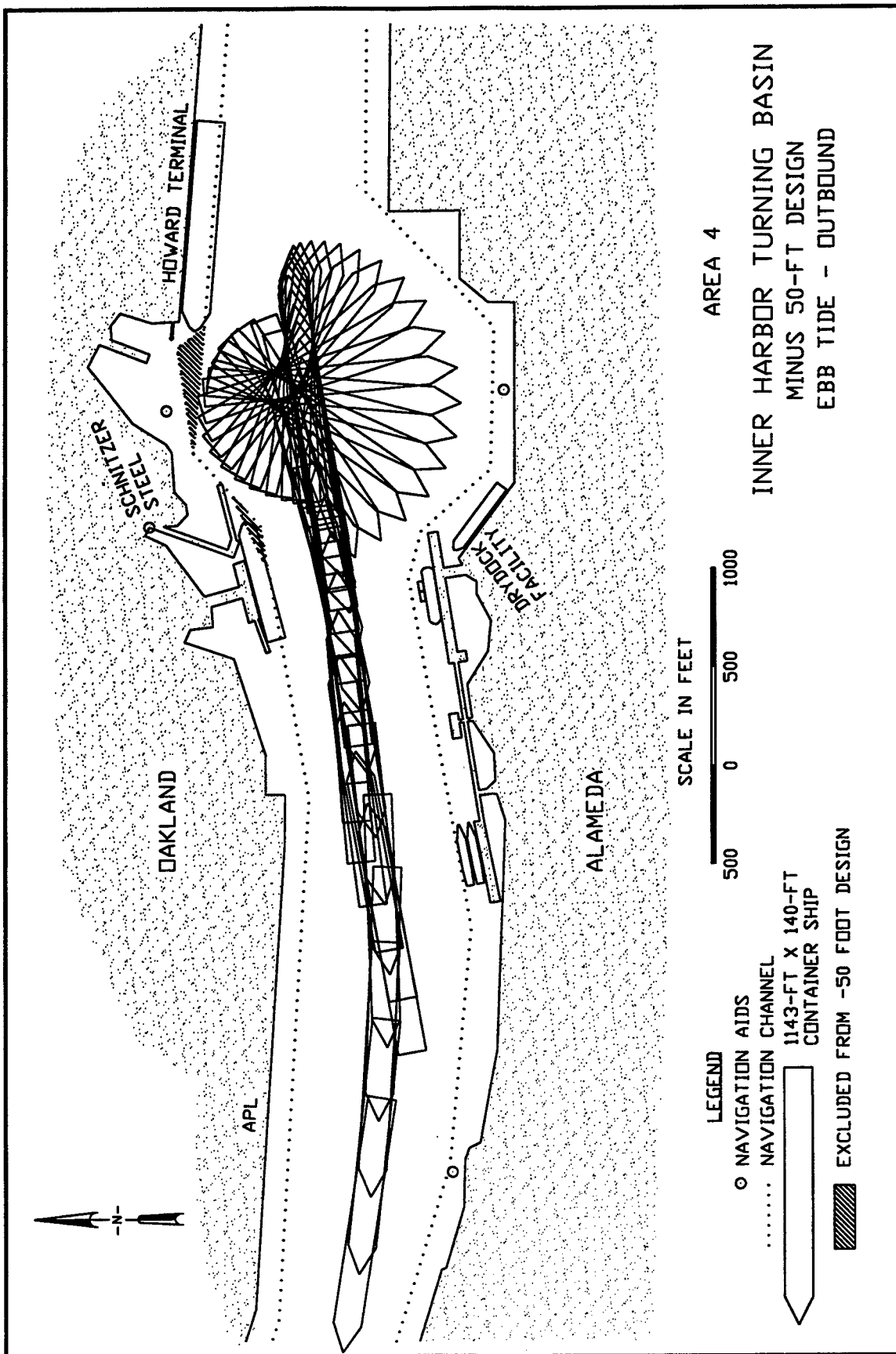


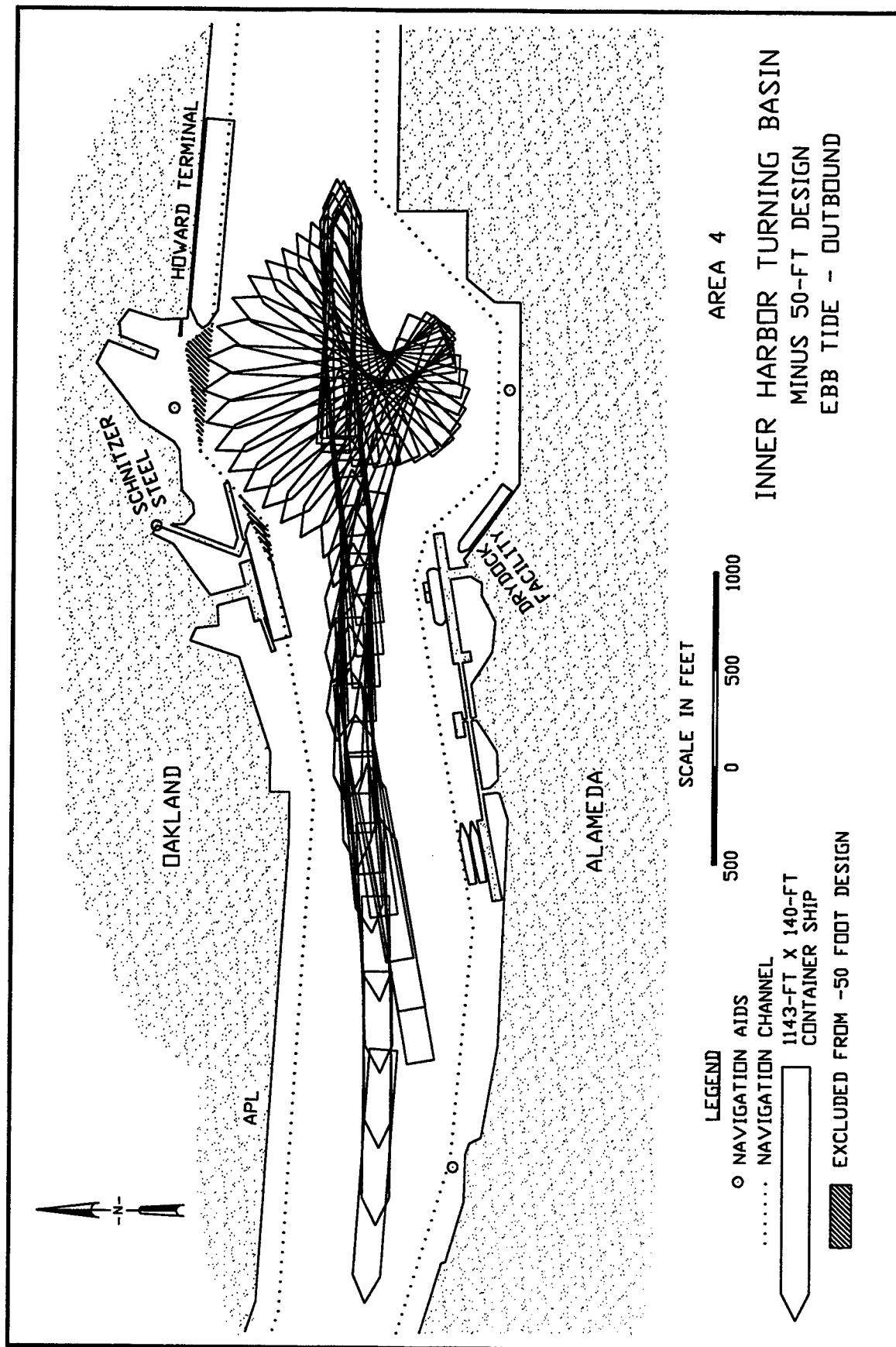


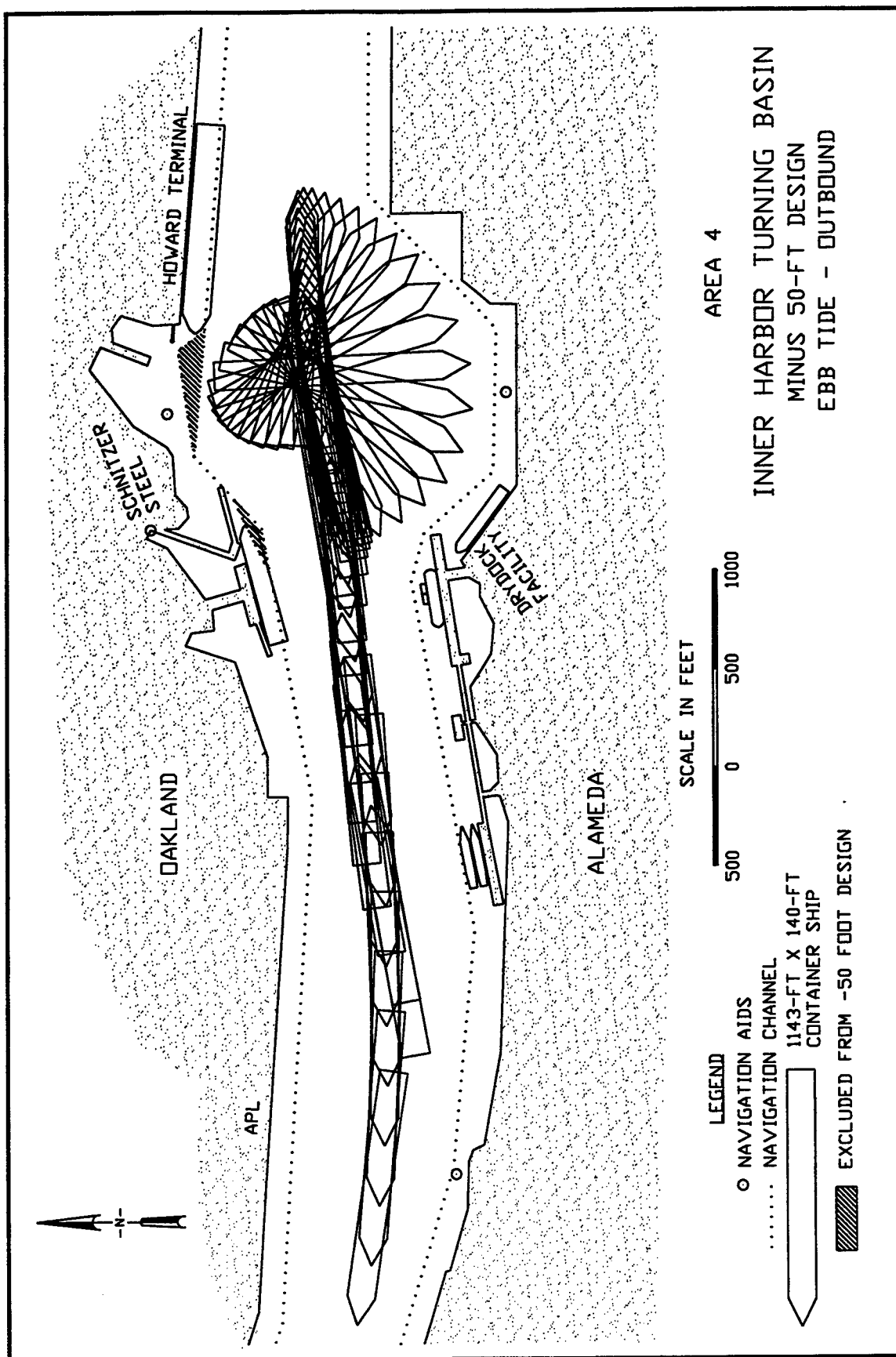


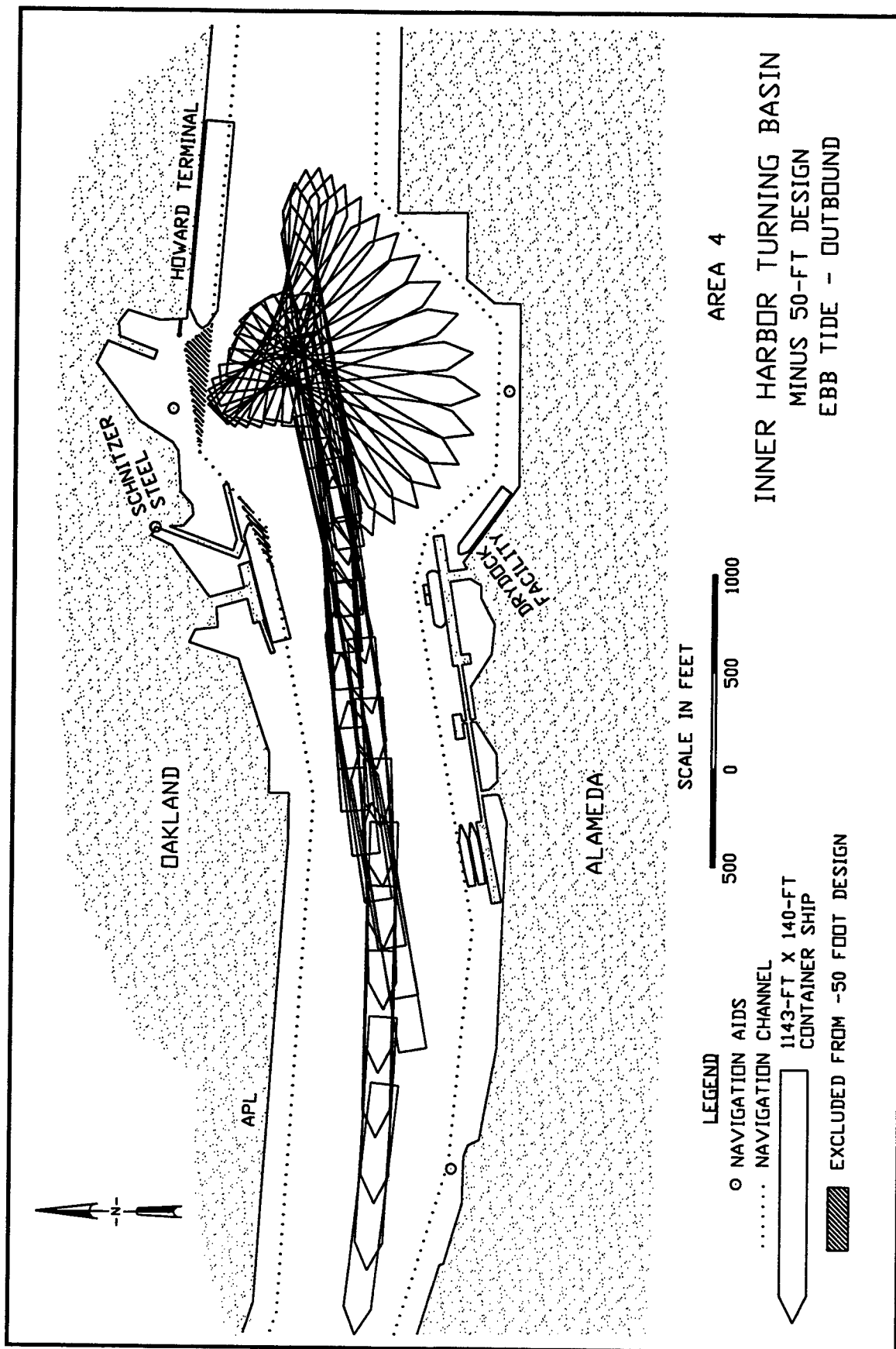


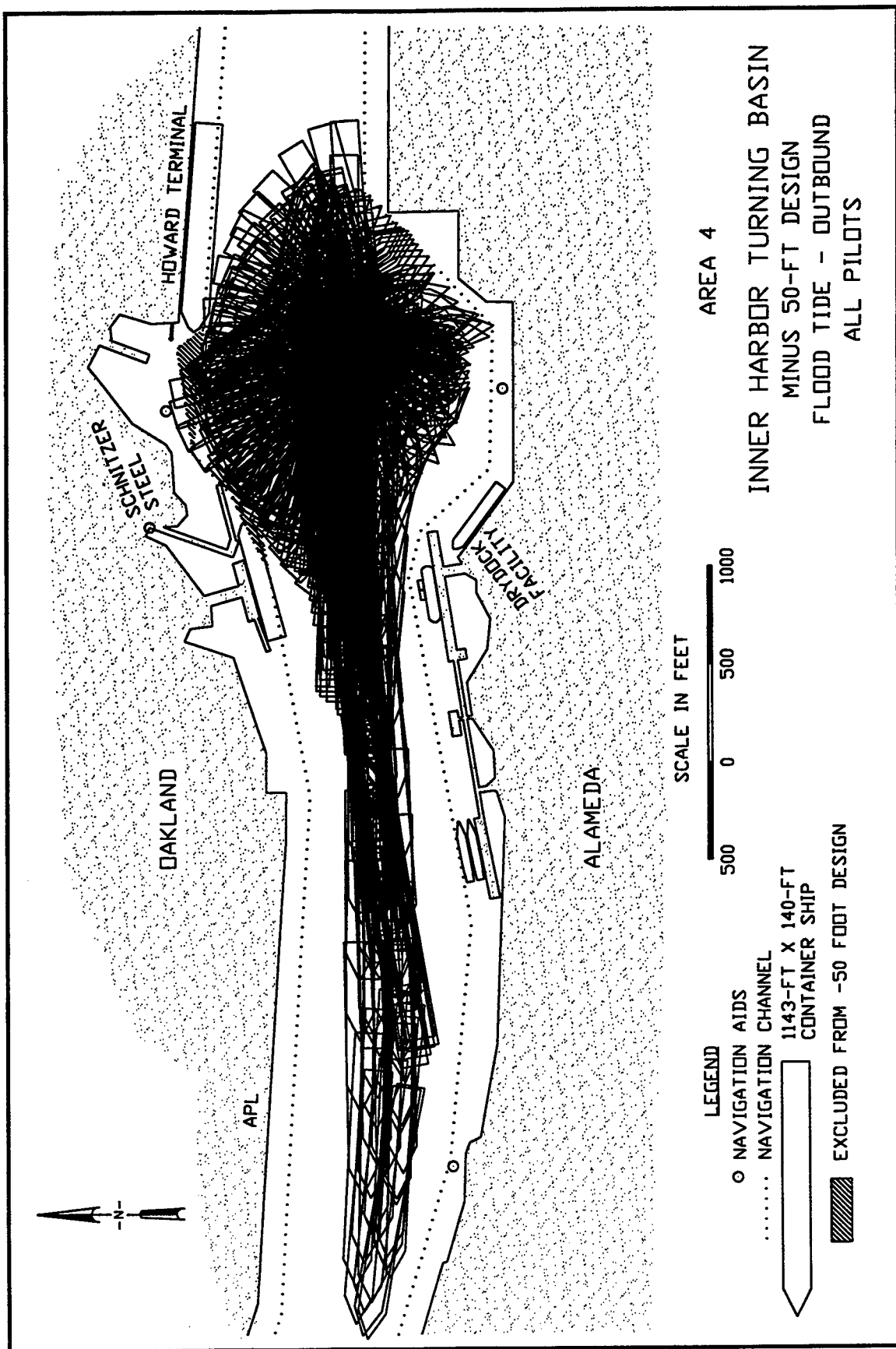


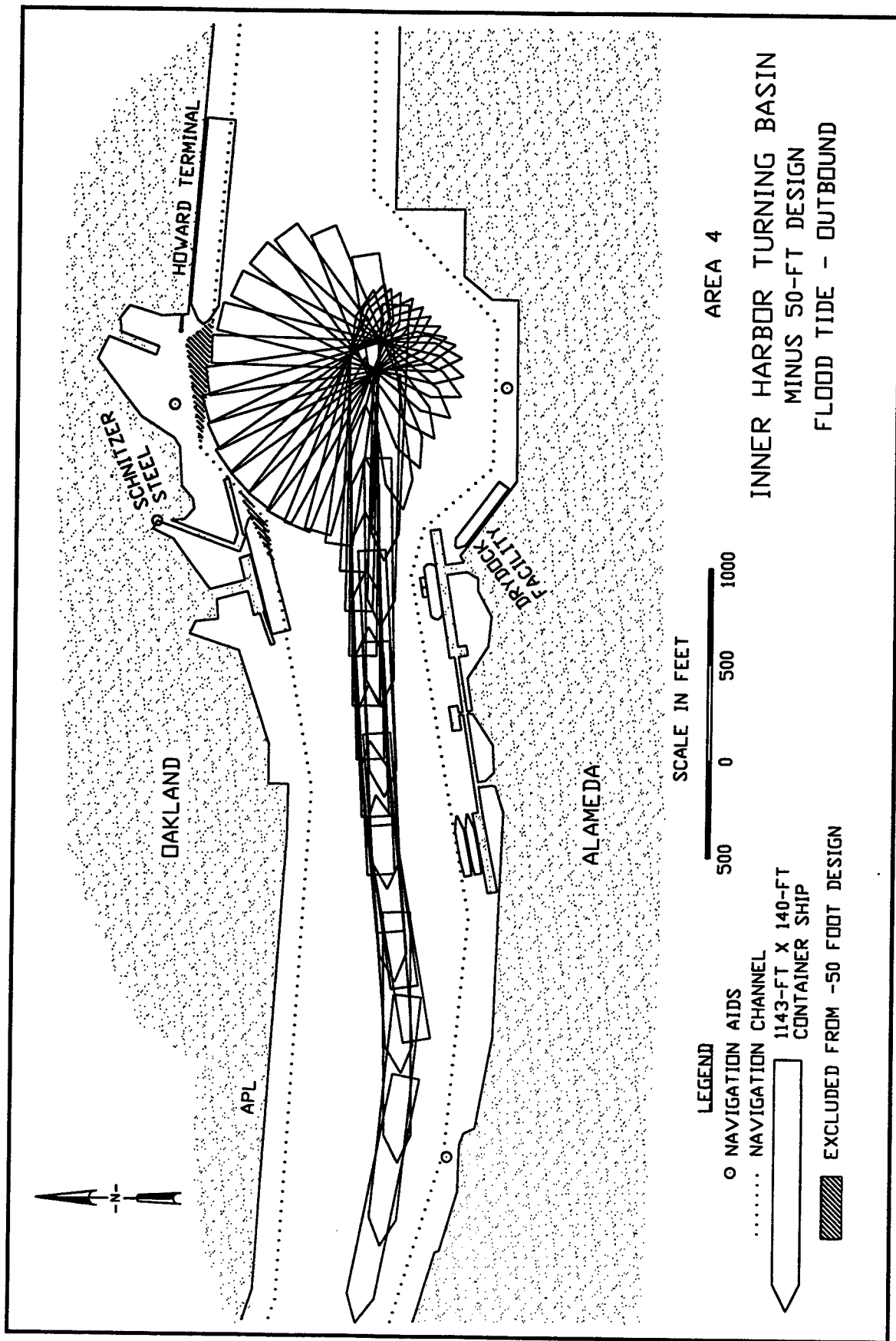


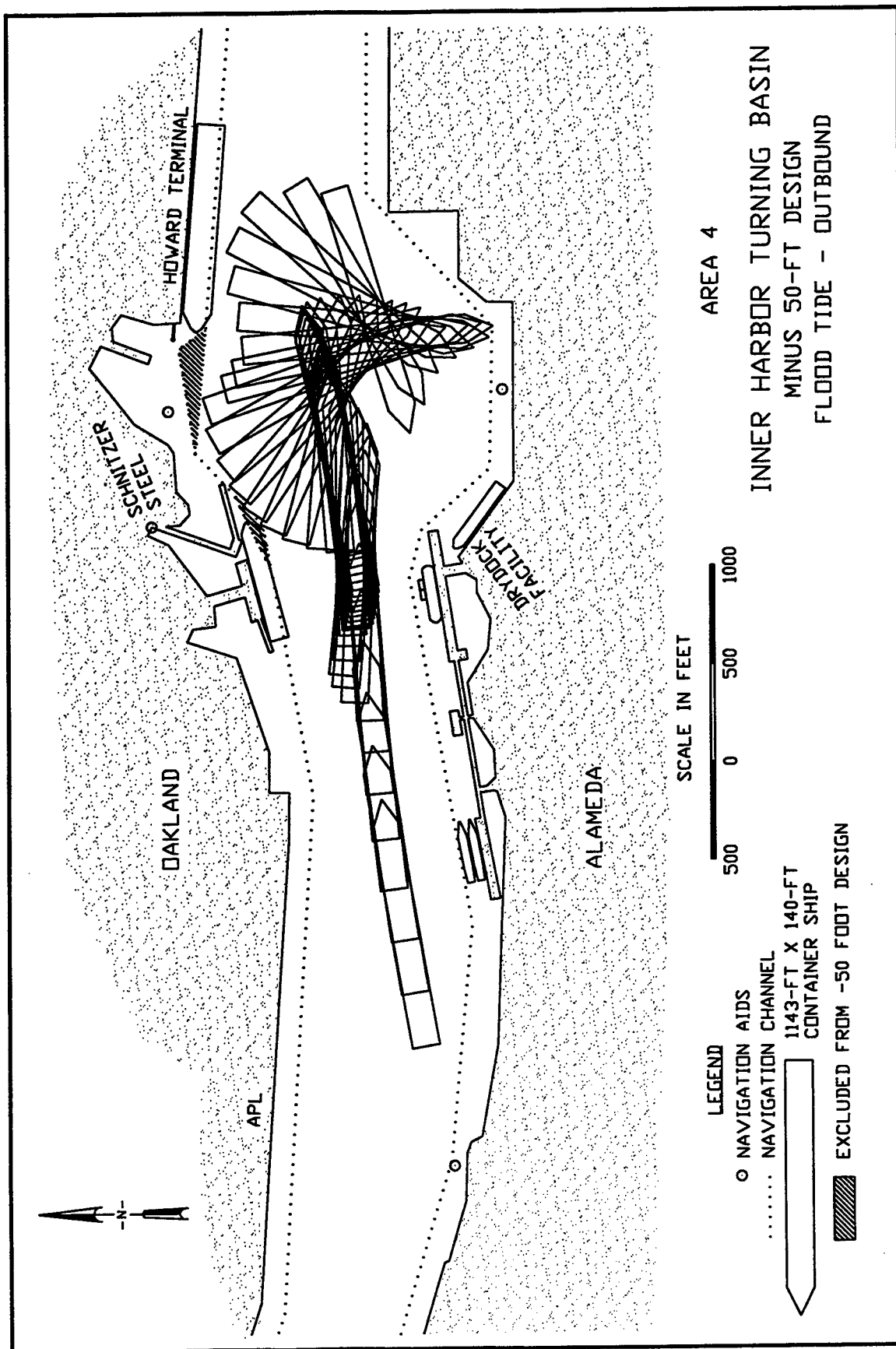


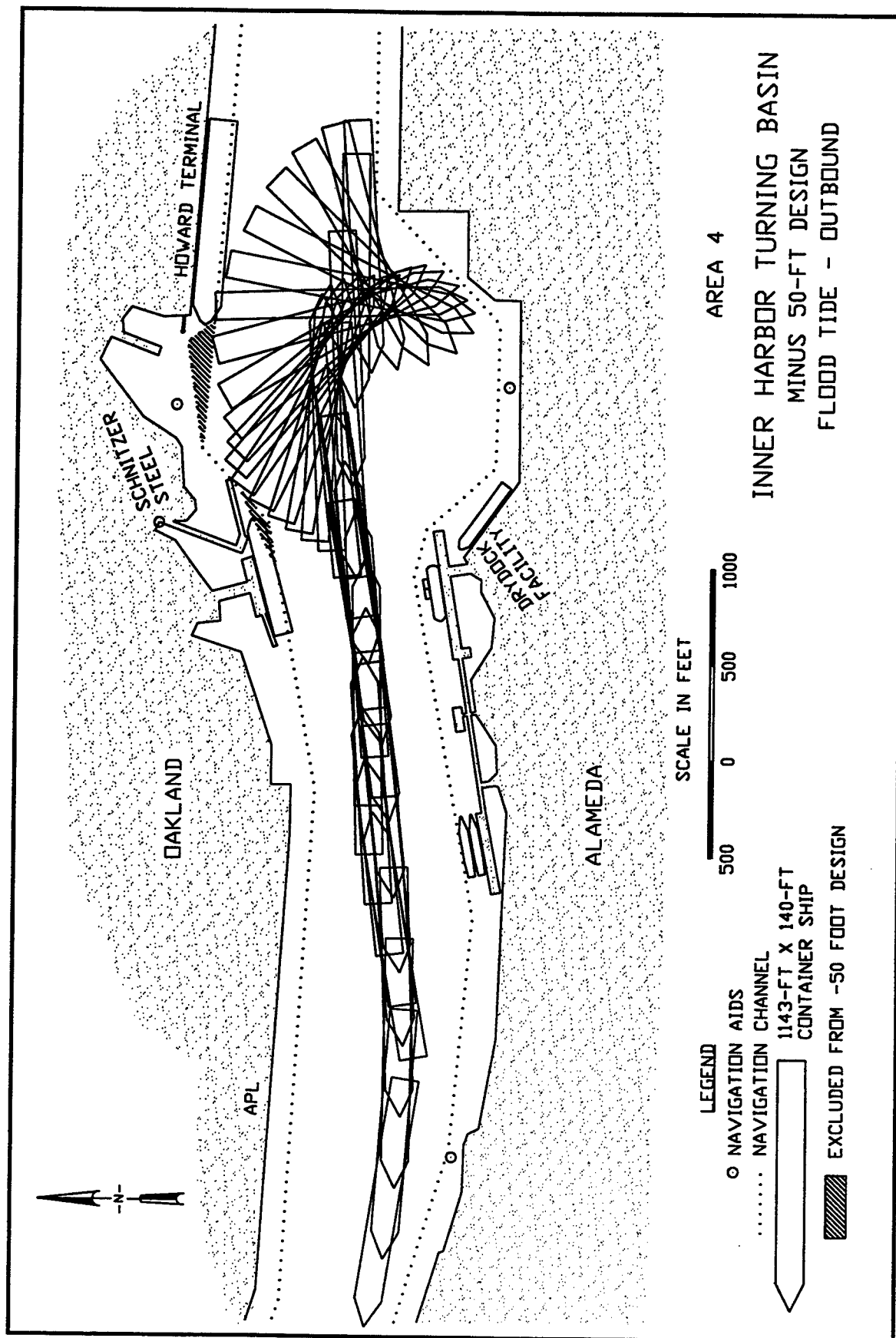


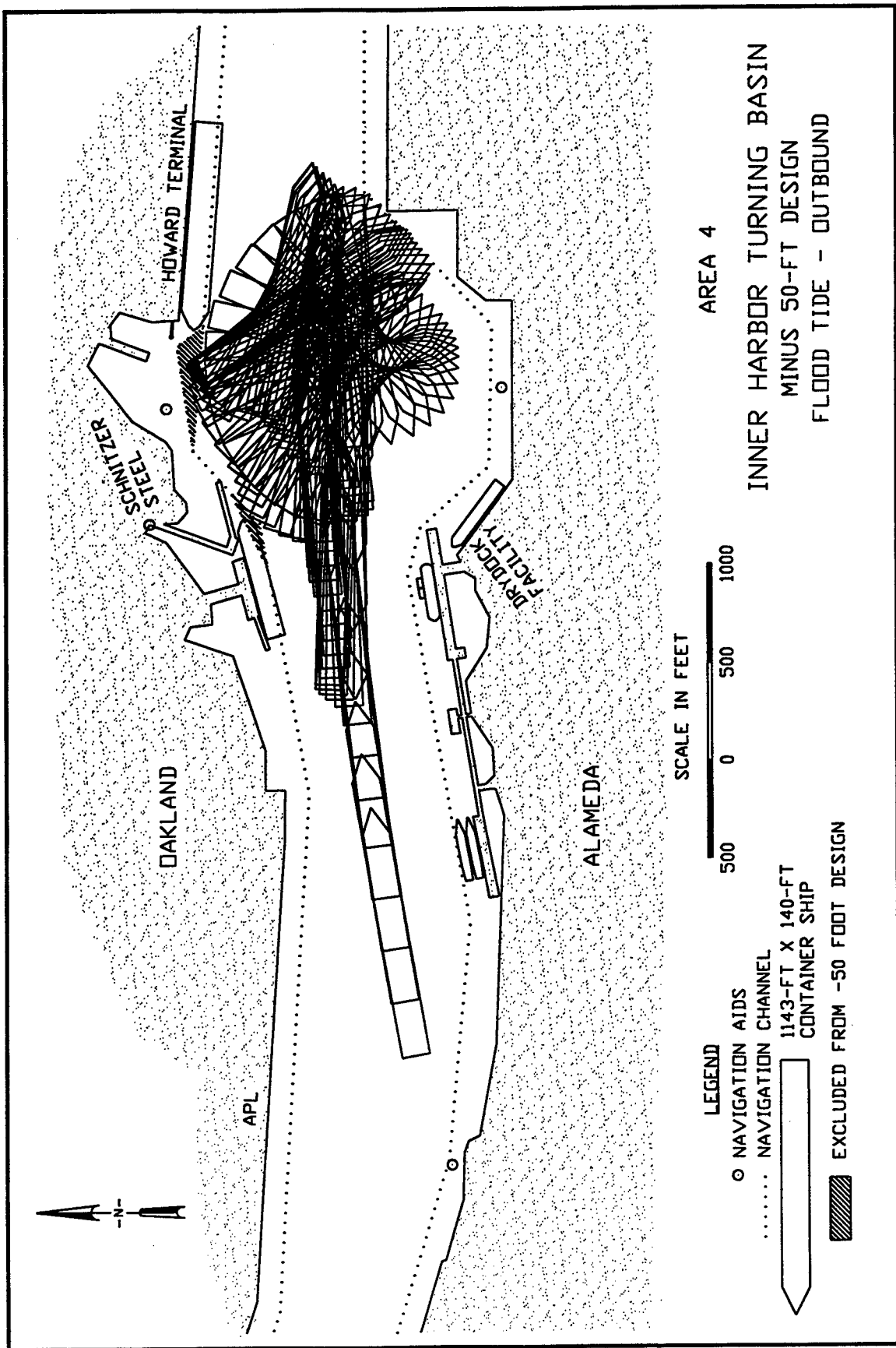


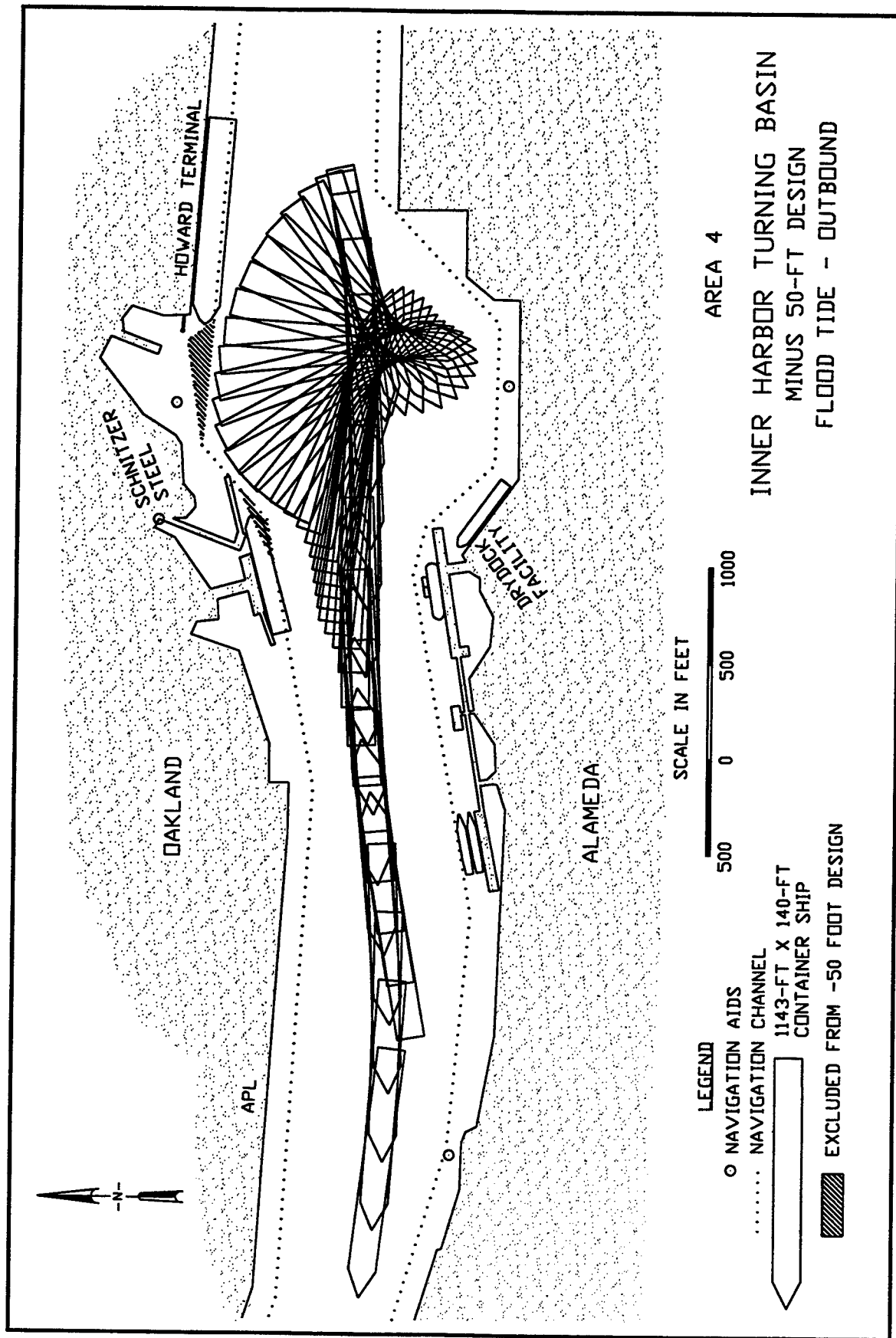


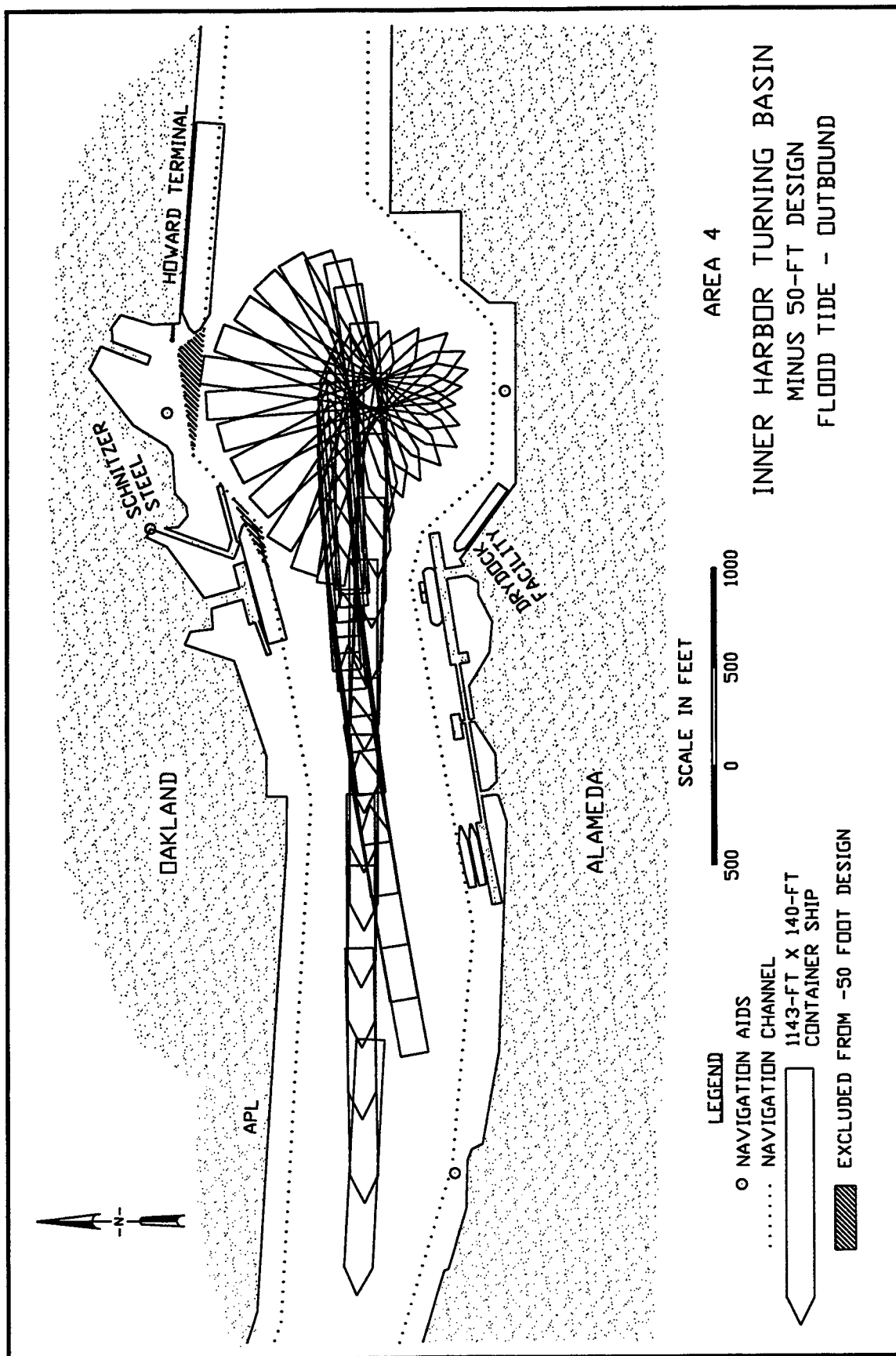


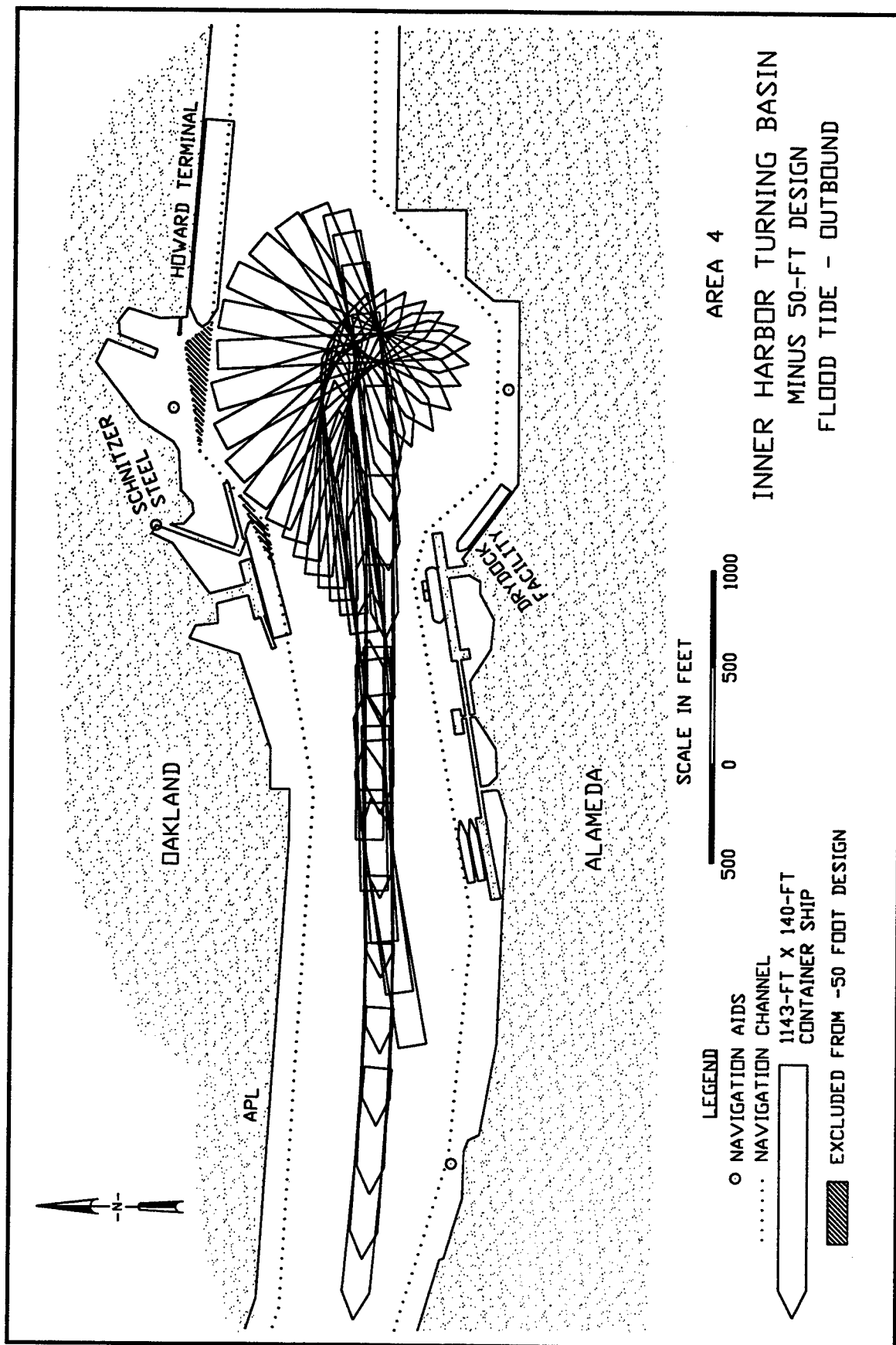


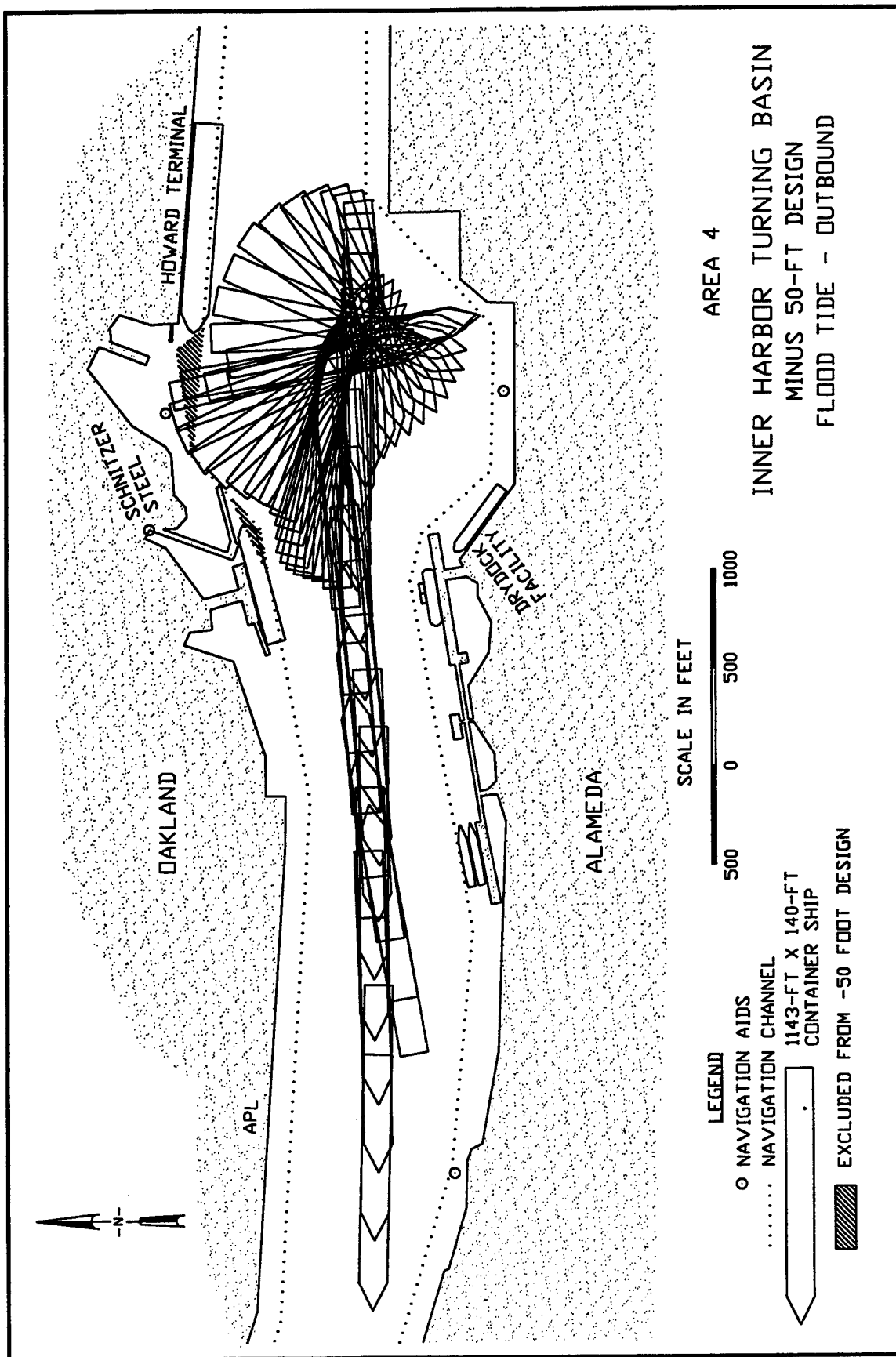


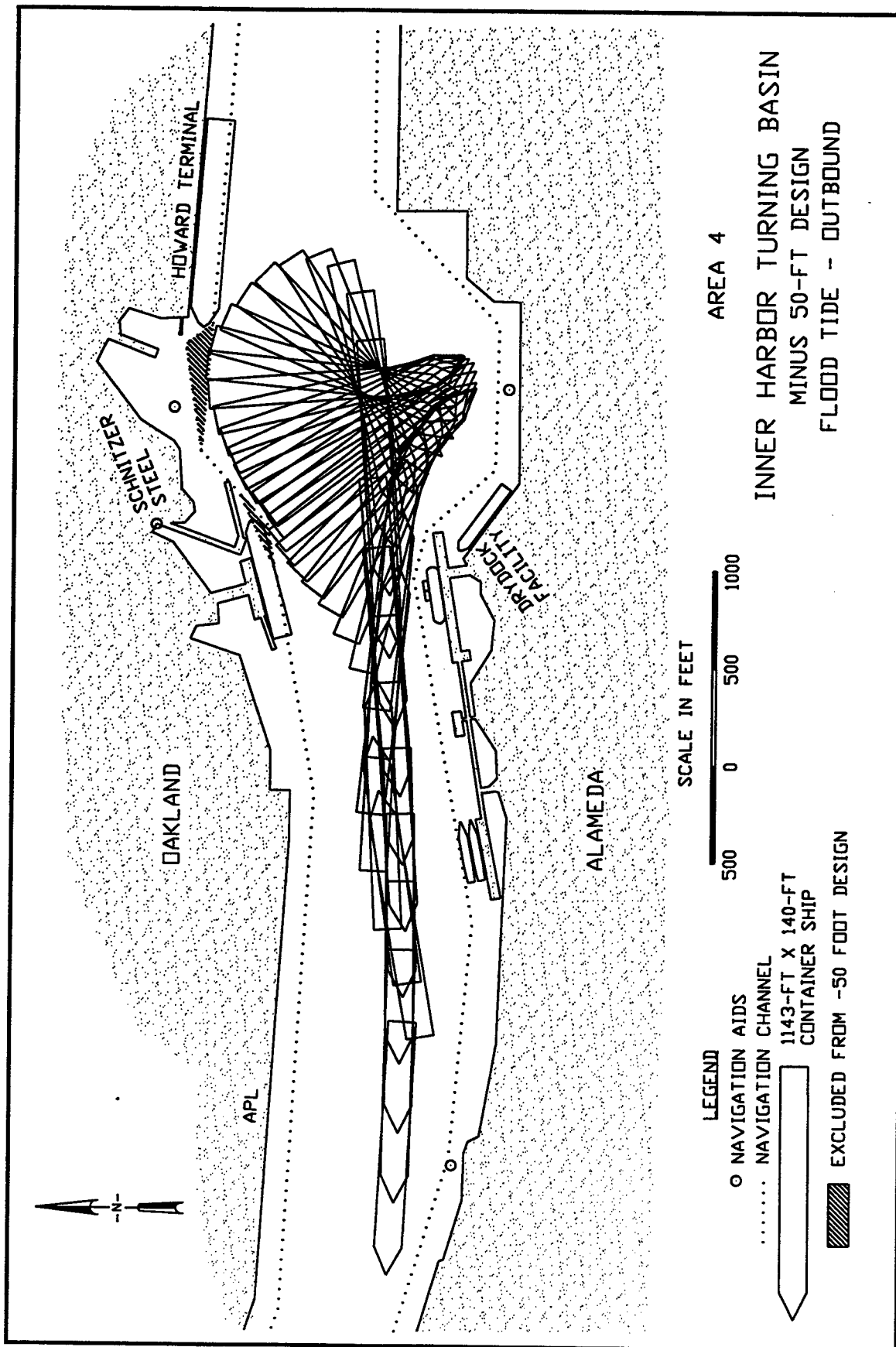












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14. ABSTRACT The Port of Oakland and the Oakland Inner and Outer Harbors are located on the eastern side of the San Francisco Bay. The Port is a transportation and distribution center that provides access to marine terminals specializing in containerized shipments. The tidal range is about 6.4 ft depth. Navigation problems arise from the cross currents or shear at the entrance to the Inner and Outer Harbor and the size of the turning basin for each harbor. A deepening of the existing Inner and Outer Harbor channels is proposed. Size constraints in the area made it necessary to provide careful modeling and analysis.					
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